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Beginning J2ME: From Novice to Professional, Third Edition

SING LI AND JONATHAN KNUDSEN

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Beginning J2ME: From Novice to Professional, Third Edition

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To Kimlan

To Andrew and Elena

Contents at a Glance

About the Authors xvii
About the Technical Reviewer xix
Acknowledgments xxi
Preface xxiii

CHAPTER 1 Introduction 1
CHAPTER 2 Building MIDlets 11
CHAPTER 3 All About MIDlets 29
CHAPTER 4 Almost the Same Old Stuff 39
CHAPTER 5 Creating a User Interface 53
CHAPTER 6 Lists and Forms 67
CHAPTER 7 Custom Items 89
CHAPTER 8 Persistent Storage I: MIDP Record Store 103
CHAPTER 9 Persistent Storage II: File Connection and PIM API 117
CHAPTER 10 Connecting to the World 143
CHAPTER 11 Wireless Messaging API 165
CHAPTER 12 Bluetooth and OBEX 195
CHAPTER 13 Programming a Custom User Interface 231
CHAPTER 14 The Game API 255
CHAPTER 15 3D Graphics 275
CHAPTER 16 Sound, Music, and Video: MMAPI 305
CHAPTER 17 Performance Tuning 331
CHAPTER 18 Protecting Network Data 343
APPENDIX MIDP API Reference 367

INDEX 421

Contents

About the Authors xvii
About the Technical Reviewer xix
Acknowledgments xxi
Preface xxiii

CHAPTER 1 Introduction 1

Understanding J2ME 1
Configurations 3
Connected Device Configuration 4
Connected, Limited Device Configuration 4
Profiles 5
Current Profiles 5
Mobile Information Device Profile 5
Platform Standardization 6
Anatomy of MIDP Applications 6
Advantages of MIDP 8
Portability 8
Security 8
MIDP Vendors 9
Fragmentation 9
Summary 10

CHAPTER 2 Building MIDlets 11

Tooling Up 11
Debugging Your MIDlets 12
Creating Source Code 12
Compiling a MIDlet 15
Preverifying Class Files 17
Sun's J2ME Wireless Toolkit Emulators 18
The Wireless Toolkit Devices 18
Running MIDlets 18
Using the Emulator Controls 19

Tour of MIDP Features 20
It's Java 20
MIDlet Life Cycle 20
Generalized User Interface 20
The Likelihood of Server-Side Components 21
Packaging Your Application 23
Manifest Information 23
Creating a MIDlet Descriptor 24
Using an Obfuscator 24
Using Ant 25
Running on a Real Device 27
Summary 27

CHAPTER 3 All About MIDlets 29

The MIDlet Life Cycle 29
Requesting a Wakeup Call 30
A Bridge to the Outside World 31
Packaging MIDlets 31
MIDlet Manifest Information 32
Application Descriptor 34
MIDlet Properties 34
MIDlet Suite Security 35
Permissions 35
Protection Domains 36
Permission Types 36
Permissions in MIDlet Suite Descriptors 36
Summary 37

CHAPTER 4 Almost the Same Old Stuff 39

No Floating Point in CLDC 1.0 39
java.lang 39
No Object Finalization 41
No Reflection 42
No Native Methods 42
No User Classloading 42
Multithreading 42
String and StringBuffer 43
Math 43
Runtime and System 44

Streams in java.io 45
Character Encodings 48
Resource Files 48
java.util 49
Collections 51
Timers 51
Telling Time 51
Summary 52

CHAPTER 5 Creating a User Interface 53

The View from the Top 53
Using Display 55
Event Handling with Commands 56
Creating Commands 57
Responding to Commands 58
A Simple Example 58
Tickers 60
Screens 61
TextBox, the Simplest Screen 61
Using Alerts 63
Summary 66

CHAPTER 6 Lists and Forms 67

Using Lists 67
Understanding List Types 67
Event Handling for IMPLICIT Lists 68
Creating Lists 69
About Images 69
Editing a List 70
Working with List Selections 71
An Example 71
Creating Advanced Interfaces with Forms 73
Managing Items 74
Understanding Form Layout 75
The Item Pantry 75
Responding to Item Changes 87
Summary 88

CHAPTER 7 Custom Items 89

Introducing CustomItem 89
CustomItem Painting 92
Showing, Hiding, and Sizing 93
Handling Events 93
Item Traversal 94
An Example 97
Summary 102

CHAPTER 8 Persistent Storage I: MIDP Record Store 103

Overview 103
Managing Record Stores 104
Opening, Closing, and Removing Record Stores 104
Sharing Record Stores 105
Record Store Size 106
Version and Timestamp 106
Working with Records 106
Adding Records 107
Retrieving Records 107
Deleting and Replacing Records 108
Getting RecordStore Record Information 108
Saving User Preferences 108
Listening for Record Changes 112
Performing RecordStore Queries 113
RecordFilter 113
RecordComparator 113
Working with RecordEnumeration 114
Keeping a RecordEnumeration Up-to-Date 115
Using Resource Files 116
Summary 116

CHAPTER 9 Persistent Storage II: File Connection and PIM API 117

File Connection Optional Package 117
Determining If FileConnection API Is Available 118
Accessing File Systems 119
Obtaining FileConnections from GCF 119
File or Directory 120
Modifying File Attributes 120

Directory and File Size 121
Creating New Files or Directories 121
Renaming and Deleting Files and Directories 121
Listing Directory Content 122
Path and URL Information 122
Listening for Card Insertion and Removal 123
Discovering the Available File Systems 124
FileConnection and Security 124
An Example 124
PIM Optional Package 130
Determining If PIM Optional Package Is Available 131
Obtaining the Singleton PIM Instance 131
Opening the PIM Lists 131
Obtaining Items from a PIM List 131
Manipulating Categories 132
Standard Fields on an Item 133
Reading Field Values 135
Adding Attributes to Field Values 136
Creating a New Contact 136
Modifying Field Values 137
Removing Contacts. 137
Working with the PIM API 138
Summary 142

CHAPTER 10 Connecting to the World 143

The Generic Connection Framework 143
Review of HTTP 145
Requests and Responses. 145
Parameters 145
GET, HEAD, and POST 145
Making a Connection with HTTP GET 146
Passing Parameters 146
A Simple Example. 147
Posting a Form with HTTP POST 149
Using Cookies for Session Tracking 152
Design Tips 157
Using HTTPS 157
Using Datagram Connections 158
Other Connection Types 159

Responding to Incoming Connections 160
Permissions for Network Connections 163
Summary 164

CHAPTER 11 Wireless Messaging API 165

Ubiquitous SMS 165
SMS: The Killer App for Wireless 165
WMA and SMS 166
WMA API 167
Creating New Messages 168
Sending Binary SMS Messages 169
Sending Text SMS Messages 170
Receiving SMS Messages 170
Calling the Blocking receive() Method 171
A Nonblocking Approach to Receiving SMS Messages 172
Examining Message Headers 172
Receiving CBS Messages 173
Working with SMS APIs 173
Sending SMS Messages 178
Multimedia Messaging with WMA 2.0 181
The Anatomy of a Multipart Message 182
Working with Multipart Messages 182
Managing Message Parts 184
Adding Message Parts to a Message 184
Accessing Content of Message Parts 185
A MIDlet to Send and Receive MMS 185
Testing MMS Send and Receive 192
Summary 194

CHAPTER 12 Bluetooth and OBEX 195

Bluetooth, CLDC, and MIDP 195
JSR 82: The Bluetooth JSR 196
Networking with Devices Near You 196
The Bluetooth Service Model 198
The Bluetooth API 199
Accessing Local Bluetooth Stack 199
Discovering Devices 201
Starting and Stopping Device Discovery 201

A Simpler Way to Discover Devices 202
Discovering Services 202
A Simpler Way to Discover Services 203
Access to Remote Devices 204
The Bluetooth Control Center 205
ServiceRecord and Service Attributes 205
Creating a Bluetooth Service 206
A Bluetooth Dating Service 207
Setting Your Dating Preferences 208
Coding the Bluetooth Client 209
Coding the Bluetooth Service 211
Infrared Communications and OBEX 215
OBEX 216
OBEX Requests 216
Obtaining OBEX Client and Server Connections 220
An OBEX Dating Service 220
Coding the OBEX Dating Service Client 221
Coding an OBEX Service 224
Summary 229

CHAPTER 13 Programming a Custom User Interface 231

The Canvas Class 231
Canvas Information 231
Painting and Repainting 232
Drawing Shapes, Text, and Images 233
Coordinate Space 233
Drawing and Filling Shapes 233
Working with Color 235
Line Styles 236
Drawing Text 237
Selecting a Font 239
Measuring Text 242
Drawing Images 243
Advanced Image Rendering 244
Images As Integer Arrays 245
Blitting 246
Clipping 246
Key Events 246
Game Actions 247

Pointer Events 249
Double Buffering 249
Multithreading and Animation 250
Summary 254

CHAPTER 14 The Game API 255

Overview 255
Driving Animation with GameCanvas 255
Polling for Key States 257
Understanding Layers 259
Managing Layers 259
Using Tiled Layers 260
Creating and Initializing a TiledLayer 261
Using Animated Tiles 262
Using Sprites 263
Animating Sprites 263
Transforming Sprites 264
Handling Collisions 266
Copying Sprites 267
Putting It All Together 267
Special Effects 272
Summary 273

CHAPTER 15 3D Graphics 275

Overview 275
Rendering 3D Graphics 276
Getting Started with 3D 277
Rotating a Triangle in 3D 279
Rotating a 3D Corner Piece 291
Immediate Mode vs. Retained Mode 297
High-Level Access to a Scene Graph via Retained Mode 297
The Elusive .m3g Serialized Scene Graph File Format 298
Creating a .m3g File 298
Working with Retained Mode 298
Loading a Retained Mode 3D World 301
Retrieving the Active Camera in the Retained Mode World 302
Rendering a Retained Mode World 302
Summary 303

CHAPTER 16 Sound, Music, and Video: MMAPI 305

Quick Start 305
Playing MP3 Music 311
MMAPI Media Concepts 311
Supported Content Types and Protocols 312
Player Life Cycle 314
Controlling Players 315
Listening for Player Events 316
Tones and Tone Sequences 316
The Mobile Media API 321
Playing Video Using the MMAPI 321
Snapping Pictures on a Camera Phone 325
Summary 329

CHAPTER 17 Performance Tuning 331

Benchmarking 331
Diagnostic Tools in the J2ME Wireless Toolkit 332
Optimizing Memory Use 335
Creating and Discarding Objects 335
Strings and StringBuffers 336
Failing Gracefully 336
Coding for Speed 337
Optimize Loops 337
Use Arrays Instead of Objects 337
Use Buffered I/O 338
Be Clean 338
Optimize the User Interface 340
Optimizing Application Deployment 340
Partition Your Application 340
Only Include Classes You Need 341
Use an Obfuscator 341
Summary 341

CHAPTER 18 Protecting Network Data 343

Cryptography Review 343
The Internet Is a Big Room 343
Data Security Needs and Cryptographic Solutions 344
HTTPS Is Almost Everything You Could Want 345

The Bouncy Castle Cryptography Package 345
Protecting Passwords with a Message Digest 346
The Problem with Passwords 346
Using a Message Digest. 346
Using the Bouncy Castle Cryptography Package 347
Implementing a Protected Password Protocol. 347
Suggested Enhancements 355
Securing Network Data 356
Using Bouncy Castle Ciphers. 358
Implementation 358
Suggested Enhancements 364
Deployment Issues 364
Trimming Bouncy Castle Down to Size 364
Summary 366

APPENDIX **MIDP API Reference** 367

INDEX 421

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Preface

This book describes how to program mobile telephones, pagers, PDAs, and other small devices using Java technology. It is about the Mobile Information Device Profile (MIDP), which is part of the Java 2 Platform, Micro Edition (J2ME). It is concise and complete, describing all of MIDP as well as moving into several exciting advanced concepts such as 3D graphics and cryptography.

This third edition covers MIDP 2.0, and has been updated to track the Java Technology for the Wireless Industry (JTWI 1.0) de facto standard. Every chapter has been revised and meticulously updated, and four completely new chapters have been added.

Who Are You?

You're probably reading this book because you're excited about building wireless applications with Java. This book is aimed at people who already have experience programming in Java. At a minimum, you should understand the Java programming language and the fundamentals of object-oriented programming. Some chapters delve into subjects that in themselves could occupy entire books. These chapters include suggested reading if you want to get up to speed on a particular subject.

If you are unfamiliar with Java, we suggest you read an introductory book or take a course. *Learning Java, Second Edition* (O'Reilly 2002) is a good introduction to Java for programmers who are already experienced in another language such as C or C++.

The Structure of This Book

This book is organized into 18 chapters and one appendix. There are basically three sections. The first two chapters are introductory material. Chapters 3 through 16 provide complete coverage of the MIDP 2.0 and JTWI 1.0 APIs, together with some of the most frequently used optional APIs available. Chapters 17 and 18 cover advanced topics. The complete breakdown of chapters is listed here:

- Chapter 1, "Introduction," provides context and motivation for the rest of the book. J2ME is explained in detail, gradually zooming in to MIDP and JTWI.
- Chapter 2, "Building MIDlets," is intended to be a teaser. It includes an example application that allows you to look up the definitions of words over the Internet using any MIDP device. Along the way you'll learn a lot about developing applications for the MIDP platform.
- Chapter 3, "All About MIDlets," goes into detail about the life cycle and packaging of MIDP applications. It includes coverage of the MIDP 2.0 security architecture.
- Chapter 4, "Almost the Same Old Stuff," describes the pieces of the MIDP API that will be familiar to Java programmers.

- Chapter 5, “Creating a User Interface,” is the first of a handful of chapters devoted to MIDP’s user interface packages. It provides an overview of MIDP’s user interface package and goes into detail about the simple visual components.
- Chapter 6, “Lists and Forms,” picks up where Chapter 5 left off, describing MIDP’s advanced user interface components.
- Chapter 7, “Custom Items,” shows how to create your own form items in MIDP.
- Chapter 8, “Persistent Storage I: MIDP Record Store,” describes MIDP’s mechanism for storing data.
- Chapter 9, “Persistent Storage II: File Connection and PIM API,” covers popular optional APIs for accessing a device’s file system, memory cards, and PIM features.
- Chapter 10, “Connecting to the World,” contains all the juicy details about how MIDP applications can send and receive data over the Internet.
- Chapter 11, “Wireless Messaging API,” describes WMA, a standard component of JTWI 1.0 that can be used to access the rich Short Message Service (SMS) and Cell Broadcast Service (CBS) available on modern wireless networks. This chapter also covers the new WMA 2.0 for working with audio and video messages via Multimedia Messaging Service (MMS).
- Chapter 12, “Bluetooth and OBEX,” provides coverage of the optional API that enables communications of devices through Bluetooth radio Personal Area Networks (PANs) and infrared links.
- Chapter 13, “Programming a Custom User Interface,” describes the low-level API that can be used for specialized application user interfaces.
- Chapter 14, “The Game API,” describes MIDP 2.0 features for creating games, including sprites and tiled layers.
- Chapter 15, “3D Graphics,” includes a hands-on, easy-to-understand introduction to the Mobile 3D Graphics optional API (M3G), providing you with a springboard into the fascinating world of 3D graphics programming on mobile devices.
- Chapter 16, “Sound, Music, and Video: MMAPI,” is about MIDP 2.0 new multimedia capabilities and the Mobile Media API (MMAPI). You’ll learn how to produce simple tones, play sampled audio data, play MP3 music, play video clips, and even take snapshots with your camera-phone.
- Chapter 17, “Performance Tuning,” describes techniques for coping with the limited resources that are available on small devices.
- Chapter 18, “Protecting Network Data,” discusses how to protect valuable data on the insecure Internet. It includes two sample applications that demonstrate cryptographic techniques for protecting data.
- Finally, the appendix, “MIDP API Reference,” contains an API reference for the classes and interfaces that make up MIDP. The method signatures for the public API of each class and interface are listed for handy quick reference.

CHAPTER 1

Introduction

Java 2 Platform, Micro Edition (J2ME) is the second revolution in Java's short history. When Java was introduced in 1995, it looked like the future of computing was in *applets*, small programs that could be downloaded and run on demand. A slow Internet and a restrictive all-or-nothing sandbox security model accounted for the initially slow adoption of applets. Java, as a platform, really took off with the advent of *servlets*, Java programs that run on a server (offering a modular and efficient replacement for the vulnerable CGI). Java further expanded into the server side of things, eventually picking up the moniker of Java 2 Platform, Enterprise Edition (J2EE). This was the first revolution, the blitz of server-side Java.

The second revolution is the explosion of small-device Java, and it's happening now. The market for small devices is expanding rapidly, and Java is important for two reasons. First, developers can write code and have it run on dozens of small devices, without change. Second, Java has important safety features for downloadable code.

Understanding J2ME

J2ME isn't a specific piece of software or specification. All it means is Java for small devices. Small devices range in size from pagers, mobile phones, and personal digital assistants (PDAs) all the way up to things like set-top boxes that are just shy of being desktop PCs.

J2ME is divided into *configurations*, *profiles*, and *optional APIs*, which provide specific information about APIs and different families of devices. A configuration is designed for a specific kind of device based on memory constraints and processor power. It specifies a Java Virtual Machine (JVM) that can be easily ported to devices supporting the configuration. It also specifies a strict subset of the Java 2 Platform, Standard Edition (J2SE) APIs that will be used on the platform, as well as additional APIs that may be necessary. Device manufacturers are responsible for porting a specific configuration to their devices.

Profiles are more specific than configurations. A profile is based on a configuration and provides additional APIs, such as user interface, persistent storage, and whatever else is necessary to develop running applications for the device.

Optional APIs define specific additional functionality that may be included in a particular configuration (or profile). The whole caboodle—configuration, profile, and optional APIs—that is implemented on a device is called a *stack*. For example, a possible future device stack might be CLDC/MIDP + Mobile Media API. See the section "Platform Standardization" later in this chapter for information on JSR 185, which defines a standard J2ME stack.

Currently, there are a handful of configurations and profiles; the most relevant ones for J2ME developers are illustrated in Figure 1-1.

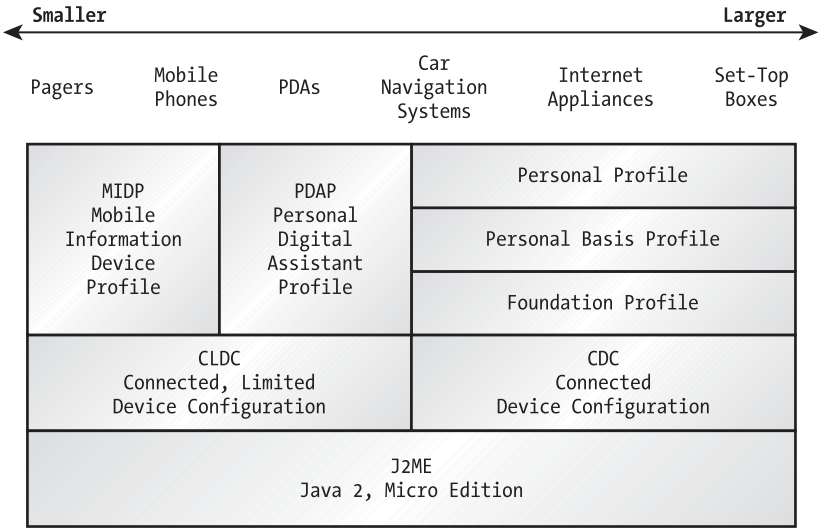


Figure 1-1. *Common J2ME profiles and configurations*

THE JAVA COMMUNITY PROCESS

The Java Community Process (JCP) is designed to ensure that Java technology is developed according to community consensus, and to avoid industry fragmentation. The process is described here:

`http://jcp.org/jsr/all/`

Configurations and profiles first appear in the world as Java Specification Requests (JSRs). You can see a list of current JSRs here:

`http://jcp.org/jsr/all/`

To give you a flavor of what's happening in the J2ME world, Table 1-1 shows some of the configurations, profiles, and optional APIs that are available and under development. This is not a comprehensive list; for more information, check out the JCP web site at `http://jcp.org/`.

Table 1-1. *J2ME Configurations, Profiles, and Optional APIs*

Configurations		
JSR	**Name**	**URL**
30	Connected, Limited Device Configuration (CLDC) 1.0	`http://jcp.org/jsr/detail/30.jsp`
139	Connected, Limited Device Configuration (CLDC) 1.1	`http://jcp.org/jsr/detail/139.jsp`
36	Connected Device Configuration 1.0.1	`http://jcp.org/jsr/detail/36.jsp`
218	Connected Device Configuration 1.1	`http://jcp.org/jsr/detail/218.jsp`

Table 1-1. *J2ME Configurations, Profiles, and Optional APIs (Continued)*

Configurations		
JSR	**Name**	**URL**
Profiles		
JSR	**Name**	**URL**
37	Mobile Information Device Profile 1.0	http://jcp.org/jsr/detail/37.jsp
118	Mobile Information Device Profile 2.0	http://jcp.org/jsr/detail/118.jsp
75	PDA Profile 1.0	http://jcp.org/jsr/detail/75.jsp
46	Foundation Profile 1.0	http://jcp.org/jsr/detail/46.jsp
129	Personal Basis Profile 1.0	http://jcp.org/jsr/detail/129.jsp
62	Personal Profile 1.0	http://jcp.org/jsr/detail/62.jsp
219	Foundation Profile 1.1	http://jcp.org/jsr/detail/219.jsp
217	Personal Basis Profile 1.1	http://jcp.org/jsr/detail/217.jsp
Optional APIs		
JSR	**Name**	**URL**
75	PDA Optional Packages for J2ME	http://jcp.org/jsr/detail/75.jsp
82	Java APIs for Bluetooth	http://jcp.org/jsr/detail/82.jsp
135	Mobile Media API 1.1	http://jcp.org/jsr/detail/135.jsp
184	Mobile 3D Graphics	http://jsp.org/jsr/detail/184.jsp
179	Location API for J2ME	http://jcp.org/jsr/detail/179.jsp
120	Wireless Messaging API 1.0	http://jcp.org/jsr/detail/120.jsp
205	Wireless Messaging API 2.0	http://jcp.org/jsr/detail/205.jsp
172	J2ME Web Services APIs	http://jsp.org/jsr/detail/172.jsp
66	RMI Optional Package	http://jcp.org/jsr/detail/66.jsp

Configurations

A configuration specifies a JVM and some set of core APIs for a specific family of devices. Currently there are two: the Connected Device Configuration (CDC) and the Connected, Limited Device Configuration (CLDC).

The configurations and profiles of J2ME are generally described in terms of their memory capacity. Usually a minimum amount of ROM and RAM is specified. For small devices, it makes sense to think in terms of volatile and nonvolatile memory. The nonvolatile memory is capable of keeping its contents intact as the device is turned on and off. ROM is one type, but nonvolatile memory could also be flash memory or battery-backed RAM. Volatile memory is essentially workspace and does not maintain its contents when the device is turned off.

Connected Device Configuration

A connected device has, at a minimum, 512KB of read-only memory (ROM), 256KB of random access memory (RAM), and some kind of network connection. The CDC is designed for devices like television set-top boxes, car navigation systems, and high-end PDAs. The CDC specifies that a full JVM (as defined in the Java Virtual Machine Specification, 2nd edition) must be supported.

CDC is developed under the Java Community Process. For more information on the CDC, see `http://java.sun.com/products/cdc/`. A Linux reference of CDC 1.0.1 implementation is available now.

CDC 1.0.1 is the basis of the Personal Profile 1.0 stack. The Personal Profile 1.0 increases the minimum memory requirement to 2.5MB of ROM and 1MB of RAM, and requires a robust network plus a GUI display on a device that can support applet display.

CDC 1.1 is currently a work in progress. It will support Personal Profile 1.1 and will introduce APIs to match the level of JDK 1.4.

Connected, Limited Device Configuration

CLDC is the configuration that interests us, because it encompasses mobile phones, pagers, PDAs, and other devices of similar size. CLDC is aimed at smaller devices than those targeted by the CDC. The name CLDC appropriately describes these devices, having limited display, limited memory, limited CPU power, limited display size, limited input, limited battery life, and limited network connection.

The CLDC is designed for devices with 160KB to 512KB of total memory, including a minimum of 160KB of ROM and 32KB of RAM available for the Java platform. If you've ever watched J2SE gobble up tens of megabytes of memory on your desktop computer, you'll appreciate the challenge of J2ME. The "Connected" simply refers to a network connection that tends to be intermittent and probably not very fast. (Most mobile telephones, for example, typically achieve data rates of 9.6Kbps.) These connections also tend to be costly, typically billed by the data packets exchanged. Between the high cost and intermittent slow network connection, applications designed in the CLDC space should be very sparing with the use of the network connection.

The reference implementation of the CLDC is based around a small JVM called the KVM (J2ME licensees may use this KVM or implement their own as long as it conforms to the CLDC). Its name comes from the fact that it is a JVM whose size is measured in kilobytes rather than megabytes. While the CLDC is a specifications document, the KVM refers to a specific piece of software.[1] Because of its small size, the KVM can't do everything a JVM does in the J2SE world.

- Native methods cannot be added at runtime. All native functionality is built into the KVM.
- The KVM only includes a subset of the standard bytecode verifier. This means that the task of verifying classes is split between the CLDC device and some external mechanism. This has serious security implications, as we'll discuss later.

1. The KVM was originally part of the Spotless system, a Sun research project. See `http://www.sun.com/research/spotless/`.

You can find more information at the CLDC home page, `http://java.sun.com/products/cldc/`. Most deployed devices implement CLDC 1.0, but CLDC 1.1 devices are making their way onto the market as this is written. CLDC 1.1 includes enhancements to CLDC 1.0, including support for floating-point data types.

Profiles

A profile is layered on top of a configuration, adding the APIs and specifications necessary to develop applications for a specific family of devices.

Current Profiles

Several different profiles are being developed under the Java Community Process. Table 1-1 (shown earlier) provides a bird's-eye view.

The Foundation Profile is a specification for devices that can support a rich networked J2ME environment. It does not support a user interface; other profiles can be layered on top of the Foundation Profile to add user interface support and other functionality.

Layered on top of the Foundation Profile are the Personal Basis Profile and the Personal Profile. The combination of CDC + Foundation Profile + Personal Basis Profile + Personal Profile is designed as the next generation of the PersonalJava application runtime environment (see `http://java.sun.com/products/personaljava/`). As such, the Personal Profile has the specific goal of backward compatibility with previous versions of PersonalJava.

The PDA Profile (PDAP), which is built on CLDC, is designed for palmtop devices with a minimum of 512KB combined ROM and RAM (and a maximum of 16MB). It sits midway between the Mobile Information Device Profile (MIDP) and the Personal Profile. It includes an application model based on MIDlets but uses a subset of the J2SE Abstract Windowing Toolkit (AWT) for graphic user interface. Although the PDAP specification is nearly finished, to our knowledge no hardware manufacturer has announced that it will be implementing PDAP. The J2ME world currently is covered by MIDP on the small end and Personal Profile on the higher end.

Mobile Information Device Profile

The focus of this book is the Mobile Information Device Profile (MIDP). According to the MIDP 2.0 specification (JSR-118), a Mobile Information Device has the following characteristics:

- A minimum of 256KB of ROM for the MIDP implementation (this is in addition to the requirements of the CLDC)
- A minimum of 128KB of RAM for the Java runtime heap
- A minimum of 8KB of nonvolatile writable memory for persistent data
- A screen of at least 96×54 pixels
- Some capacity for input, either by keypad, keyboard, or touch screen
- Two-way network connection, possibly intermittent

Try to imagine a device that might be a MIDP device: mobile telephones and advanced pagers are right in the groove, but entry-level PDAs could also fit this description.

More information about MIDP, including a link to the official specification document, is at `http://java.sun.com/products/midp/`. There are two versions of MIDP: MIDP 1.0 (JSR 37), and MIDP 2.0 (JSR 118). Many of the currently available devices do and all new devices will support MIDP 2.0. Compared to MIDP 1.0, MIDP 2.0 features a number of enhancements, including support for multimedia, a new game user interface API, support for HTTPS connection, and other features. Most importantly, MIDP 2.0 is fully backward compatible with MIDP 1.0.

JTWI standard compliance requires devices to implement MIDP 2.0 (see the next section on platform standardization). This book's focus will be on MIDP 2.0. We will mention MIDP 1.0 differences only in this introductory chapter as background information.

Platform Standardization

Given the profusion of configurations, profiles, and especially optional APIs, how do you know what APIs are likely to be available on typical devices? Sun's answer to this question is JSR 185 (`http://jcp.org/jsr/detail/185.jsp`), impressively titled *Java Technology for the Wireless Industry (JTWI)*. This specification attempts to standardize software stacks to bring coherence to the J2ME world. A reference implementation and a TCK (kit for compatibility testing) of the unified software stack is made available with JSR 185. As currently specified, a JTWI-compliant device must have MIDP 2.0 with CLDC 1.0 (or CLDC 1.1), and must support WMA (Wireless Messaging API 1.0—JSR 120). If a JTWI device exposes video or audio API to applications, they must also support Mobile Media API (MMAPI).

In the next generation of J2ME, a concept called Building Blocks is supposed to replace configurations and profiles. A *Building Block* is just some subset of a J2SE API. For example, one Building Block might be created from a subset of the J2SE `java.io` package. Conceptually, a Building Block represents a smaller chunk of information than a configuration. Profiles, then, will be built on top of a set of Building Blocks rather than a configuration.

The definition of Building Blocks is a JSR, which is briefly described here: `http://jcp.org/jsr/detail/68.jsp`. Progress on JSR 68 has been extremely slow since its creation in June 2000.

In the meantime, JSR 185 will better serve as a standardization platform. Recently, leveraging the success of the JTWI work, Nokia and Vodafone have submitted a new JSR, JSR-248: Mobile Service Architecture for CDC (`http://jcp.org/jsr/detail/248.jsp`), to define a new standard software stack for the next generation of mobile devices.

Anatomy of MIDP Applications

The APIs available to a MIDP application come from packages in both CLDC and MIDP, as shown in Figure 1-2. Packages marked with a + are new in CLDC 1.1 and MIDP 2.0.

CLDC defines a core of APIs, mostly taken from the J2SE world. These include fundamental language classes in `java.lang`, stream classes from `java.io`, and simple collections from `java.util`. CLDC also specifies a generalized network API in `javax.microedition.io`.

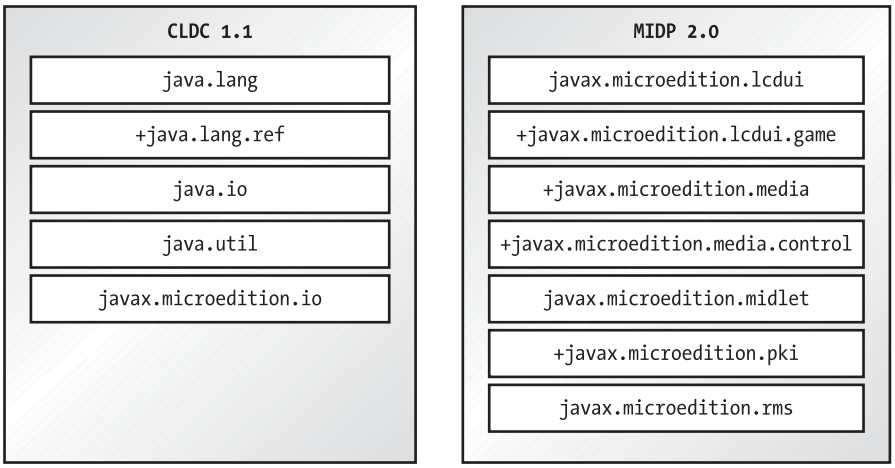


Figure 1-2. *MIDP packages*

Note While the MIDP 2.0 specification suggests that MIDP 2.0 will most likely be paired with CLDC 1.1, the JTWI compatibility platform only requires implementation atop CLDC 1.0. As a result, most current implementations of MIDP 2.0 are paired with CLDC 1.0. Historically, the MIDP 2.0 specification was moving faster through the Java Community Process than the CLDC 1.1 specification.

Optionally, device vendors may also supply Java APIs to access device-specific features. MIDP devices, then, will typically be able to run several different flavors of applications. Figure 1-3 shows a map of the possibilities.

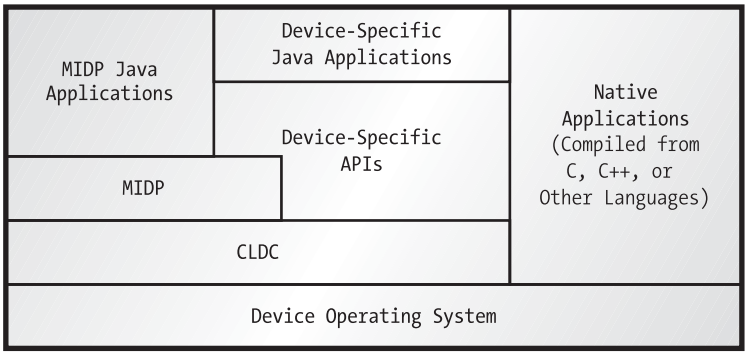


Figure 1-3. *MIDP software components*

Each device implements some kind of operating system (OS). Native applications run directly on this layer and represent the world before MIDP—many different kinds of devices, each with its own OS and native applications.

Layered on top of the device OS is the CLDC (including the JVM) and the MIDP APIs. MIDP applications use only the CLDC and MIDP APIs. Device-specific Java applications may also use Java APIs supplied by the device vendor.

Advantages of MIDP

Given the spectrum of configurations and profiles, why is this book about MIDP? First, MIDP comes at a critical time, a time when MIDP devices, like mobile phones, are an exploding market. Simultaneously, MIDP devices are achieving the kind of processing power, memory availability, and Internet connectivity that makes them an attractive platform for mobile networked applications. MIDP is already deployed on millions of handsets all over the world.

Second, of course, MIDP is the first J2ME profile that is ready for prime time. You will start writing applications as soon as you head into the next chapter!

Portability

The advantage of using Java over using other tools for small device application development is portability. You could write device applications with C or C++, but the result would be specific to a single platform. An application written using the MIDP APIs will be directly portable to any MIDP device.

If you've been following Java's development for any time, this should sound familiar. It's the same "Write Once, Run Anywhere" (WORA) mantra that Sun's been repeating since 1995. Unfortunately, WORA is a bit of a four-letter word for developers who struggled with cross-platform issues in JDK 1.0 and JDK 1.1 (particularly the browser implementations). While Java's cross-platform capabilities in Java 2 are generally successful, WORA still has the taint of an unfulfilled promise.

Does MIDP deliver painless cross-platform functionality? Yes. There will always be platform-specific bugs in MIDP implementations, but we believe MIDP works as advertised because it is so much smaller than desktop Java. Less code means fewer bugs when porting to multiple platforms. Most of the cross-platform incompatibilities of JDK 1.0 and JDK 1.1 were caused by the nightmare of trying to fit disparate windowing systems into the AWT's peer-based component architecture. MIDP has nothing approaching the complexity of AWT, which means there's an excellent possibility that MIDP applications will seamlessly run on multiple platforms right out of the starting gate. Furthermore, while the JDK 1.0 test suite only included a few dozen tests, the MIDP compatibility test suite includes several thousand tests.

Security

A second compelling reason for using Java for small device development is security. Java is well known for its ability to safely run downloaded code like applets. This is a perfect fit—it's easy to imagine nifty applications dynamically downloading to your mobile phone.

But it's not quite such a rosy picture. For one thing, the JVM used in the CLDC only implements a partial bytecode verifier, which means that part of the important task of bytecode verification must be performed off the MIDP device.

Second, the CLDC does not allow for application-defined classloaders. This means that most dynamic application delivery is dependent on device-specific mechanisms.

MIDP applications do offer one important security promise: they can never escape from the confines of the JVM. This means that, barring bugs, a MIDP application will never be able to write to device memory that doesn't belong to the JVM. A MIDP application will never mess up another application on the same device or the device OS itself.[2] This is the killer feature of MIDP. It allows manufacturers and carriers to open up application development to the world, more or less free from certification and verification programs, without the fear that rogue coders will write applications that crash phones.

In MIDP 2.0, MIDlet suites can be cryptographically signed, and then verified on the device, which gives users some security about executing downloaded code. A new permissions architecture also allows the user to deny untrusted code access to certain API features. For example, if you install a suspicious-looking MIDlet suite on your phone, it will only be able to make network connections if you explicitly allow it to do so.

MIDP Vendors

Several large players have thrown their weight behind MIDP. A quick browse of the JSR page for MIDP exposes the most important companies.

Two Asian companies led the charge to provide network services for Java-enabled mobile phones. In Korea, LG TeleCom deployed a service called ez-i in mid-2000. Later that same year, NTT DoCoMo deployed their wildly popular i-mode. The APIs developed for LG TeleCom (KittyHawk) and NTT DoCoMo (i-Appli) are similar to MIDP but were completed before the MIDP 1.0 specification.

In the United States, Motorola was the first manufacturer to produce a MIDP telephone. The i50sx and i85s were released on April 2, 2001, with service provided by Nextel. Motorola has since expanded its offerings with a handful of new devices.

Nokia has also made serious commitments to MIDP, and the expert group that created the MIDP specification includes an impressive list of manufacturers—Ericsson, Hitachi, Nokia, Sony, Symbian, and many more. You can go read the industry predictions if you wish—a gazillion MIDP phones sold in the next three years, and so on. It's a safe bet that your MIDP application will have a large market. For a comprehensive listing of MIDP devices, visit `http://wireless.java.sun.com/device/`.

Fragmentation

Platform fragmentation is a serious concern in the MIDP community. Many devices that implement MIDP 1.0 also include device-specific APIs. These APIs access device-specific features or provide functionality that wasn't addressed in MIDP 1.0's least-common-denominator specification. Current software vendors, particularly game developers, sometimes create and distribute multiple versions of an application, each tailored to a specific platform. Obviously this is a concern: part of the point of using MIDP in the first place is the ability to write one set of code and deploy it on multiple platforms.

---

2. A MIDP application could conceivably launch a denial-of-service attack (that is, sucking up all the processor's time or bringing the device OS to a standstill). It's widely acknowledged that there's not much defense against denial-of-service attacks. Applications and applets in J2SE suffer from the same vulnerability.

MIDP 2.0 addresses a long list of the shortcomings inherent with MIDP 1.0. Its timing is good, so the current adoption and deployment of MIDP 2.0 devices should provide a standard, unified platform for wireless development.

Another fragmentation issue is the confusion surrounding the assembly of configurations, profiles, and optional APIs into a software stack. As a developer, you want to understand exactly what set of APIs will be available or are likely to be available, but there seem to be so many choices and so many possibilities. The standardization on a software stack, via JTWI (JSR 185—`http://jcp.org/jsr/detail/185.jsp`), should bring clarity to this issue.

Summary

J2ME is the Java platform for small devices, a broad field that covers pretty much everything smaller than a breadbox. Because J2ME spans such a diverse selection of hardware, it is divided into configurations, profiles, and optional APIs. A configuration specifies a subset of J2SE functionality and the behavior of the JVM, while profiles are generally more specific to a family of devices with similar characteristics. Optional APIs offer added functionality in a flexible package. The Mobile Information Device Profile, which is the focus of this book, includes APIs for devices like mobile phones and two-way pagers.

CHAPTER 2

Building MIDlets

MIDP applications are piquantly called MIDlets, a continuation of the naming theme begun by applets and servlets. Writing MIDlets is relatively easy for a moderately experienced Java programmer. After all, the programming language is still Java. Furthermore, many of the fundamental APIs from `java.lang` and `java.io` are basically the same in the MIDP as they are in J2SE. Learning the new APIs (in the `javax.microedition` hierarchy) is not terribly difficult, as you'll see in the remainder of this book.

The actual development process, however, is a little more complicated for MIDlets than it is for J2SE applications. Beyond a basic compile-and-run cycle, MIDlets require some additional tweaking and packaging. The complete build cycle looks like this: Edit Source Code ➤ Compile ➤ Preverify ➤ Package ➤ Test or Deploy.

To show how things work, and to give you a taste of MIDlet development, this chapter is dedicated to building and running a simple MIDlet. In later chapters, we'll delve into the details of the MIDP APIs. In this chapter, you'll get a feel for the big picture of MIDlet development.

Tooling Up

MIDlets are developed on regular desktop computers, although the MIDlet itself is designed to run on a small device. To develop MIDlets, you'll need some kind of development kit, either from Sun or another vendor. Remember, MIDP is only a specification; vendors are free to develop their own implementations.

The world is full of MIDlet development tools if you know where to look. Furthermore, many of these tools are freely available.

The bare bones set of tools is Sun's MIDP reference implementation. This includes the `preverify` tool (more on this later), a MIDP device emulator, source code, and documentation. You can download the MIDP reference implementation by following the links from `http://java.sun.com/products/midp/`. However, we don't recommend using the reference implementation unless you really enjoy being in the middle of the gritty details of building and packaging MIDlets. (You should also investigate the reference implementation if you are interested in porting the MIDP runtime to a new device or platform.)

A much better tool for beginners is Sun's J2ME Wireless Toolkit, available from `http://java.sun.com/products/j2mewtoolkit/`. The J2ME Wireless Toolkit (or J2MEWTK, as it's affectionately known) includes a GUI tool that automates some of the tedious details of building and packaging MIDlets, providing a simple path from source code to running MIDlets. At the same time, the J2ME Wireless Toolkit is a relatively lightweight solution, almost a miniature IDE, not something that will choke your machine.

Larger IDEs are available in abundance, from device manufacturers, wireless carriers, IDE vendors, and open source communities including the following:

- Borland JBuilder X Mobile Edition:

  `http://www.borland.com/mobile/jbuilder/index.html`

- IBM WebSphere Studio Device Developer:

  `http://www-306.ibm.com/software/wireless/wsdd/`

- Research In Motion BlackBerry Java Development Environment:

  `http://www.blackberry.com/developers/na/java/tools/jde/index.shtml`

- Sun Java Studio Mobility:

  `http://wwws.sun.com/software/products/jsmobility/index.html`

- NetBeans IDE 4.x:

  `http://www.netbeans.org/`

- Eclipse J2ME Plugin:

  `http://eclipseme.sourceforge.net/`

- Nokia Developer's Suite for J2ME:

  `http://www.forum.nokia.com/main/0,6566,034-2,00.html`

You can use whatever development kit you wish. We suggest you start with the J2ME Wireless Toolkit, which is easy to use and authoritative. We'll be using the J2ME Wireless Toolkit (version 2.2, or WTK 2.2) throughout the rest of the book. Other development environments generally use the J2ME Wireless Toolkit as a plug-in anyhow, so your experiences are likely to be similar no matter what tool you use. You'll notice details about the development environment most in this chapter, where we'll go into detail about the build tools and the emulators. For much of the remainder of this book, we'll be describing the MIDP APIs, so it won't really matter which development kit you use.

Debugging Your MIDlets

If you are using any of the previously listed IDEs, you will have an integrated full-featured debugger for stepping through and debugging your MIDlets. If you are using the WTK standalone, and an external text editor, you can debug most of your MIDlets using the familiar `System.out.println()` call to output to console. The WTK maintains a console that will show all your debug and stack traces.

Creating Source Code

Writing Java source code is the same as it always was: use your favorite text editor to create a source file with a `.java` extension. The example we'll build and run is `Jargoneer`, a MIDlet that looks up words in the Jargon File. The Jargon File is a comprehensive lexicon of hacker slang (find out more by visiting `http://www.catb.org/~esr/jargon/`).

When you enter a word into Jargoneer, it connects to a server to find the definition. Running this MIDlet will allow you to appear cool in the company of your hacker friends. When someone uses an unfamiliar word, like "cruft" or "grok," you can surreptitiously key the word into your mobile phone and see a definition in a few seconds.

Jargoneer's source code is provided in Listing 2-1. If you don't want to type it in, you can download all of the code examples in this book from the Downloads page at http://www.apress.com.

Listing 2-1. *Jargoneer's Source Code*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class Jargoneer extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;

  private Command mExitCommand, mFindCommand, mCancelCommand;

  private TextBox mSubmitBox;
  private Form mProgressForm;
  private StringItem mProgressString;

  public Jargoneer() {
    mExitCommand = new Command("Exit", Command.EXIT, 0);
    mFindCommand = new Command("Find", Command.SCREEN, 0);
    mCancelCommand = new Command("Cancel", Command.CANCEL, 0);

    mSubmitBox = new TextBox("Jargoneer", "", 32, 0);
    mSubmitBox.addCommand(mExitCommand);
    mSubmitBox.addCommand(mFindCommand);
    mSubmitBox.setCommandListener(this);

    mProgressForm = new Form("Lookup progress");
    mProgressString = new StringItem(null, null);
    mProgressForm.append(mProgressString);
  }

  public void startApp() {
    mDisplay = Display.getDisplay(this);

    mDisplay.setCurrent(mSubmitBox);
  }
```

```
  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}

  public void commandAction(Command c, Displayable s) {
    if (c == mExitCommand) {
      destroyApp(false);
      notifyDestroyed();
    }
    else if (c == mFindCommand) {
      // Show the progress form.
      mDisplay.setCurrent(mProgressForm);
      // Kick off the thread to do the query.
      Thread t = new Thread(this);
      t.start();
    }
  }

  public void run() {
    String word = mSubmitBox.getString();
    String definition;

    try { definition = lookUp(word); }
    catch (IOException ioe) {
      Alert report = new Alert(
          "Sorry",
          "Something went wrong and that " +
          "definition could not be retrieved.",
          null, null);
      report.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(report, mSubmitBox);
      return;
    }

    Alert results = new Alert("Definition", definition,
        null, null);
    results.setTimeout(Alert.FOREVER);
    mDisplay.setCurrent(results, mSubmitBox);
  }

  private String lookUp(String word) throws IOException {
    HttpConnection hc = null;
    InputStream in = null;
    String definition = null;
```

```
    try {
      String baseURL = "http://65.215.221.148:8080/wj2/jargoneer?word=";
      String url = baseURL + word;
      mProgressString.setText("Connecting...");
      hc = (HttpConnection)Connector.open(url);
      hc.setRequestProperty("Connection", "close");
      in = hc.openInputStream();

      mProgressString.setText("Reading...");
      int contentLength = (int)hc.getLength();
      if (contentLength == -1) contentLength = 255;
      byte[] raw = new byte[contentLength];
      int length = in.read(raw);

      // Clean up.
      in.close();
      hc.close();

      definition = new String(raw, 0, length);
    }
    finally {
      try {
        if (in != null) in.close();
        if (hc != null) hc.close();
      }
      catch (IOException ignored) {}
    }

    return definition;
  }
}
```

Compiling a MIDlet

Writing MIDlets is an example of cross-compiling, where you compile code on one platform and run it on another. In this case, you'll be compiling a MIDlet using J2SE on your desktop computer. The MIDlet itself will run on a mobile phone, pager, or other mobile information device that supports MIDP.

The J2ME Wireless Toolkit takes care of the details as long as you put the source code in the right directory.

1. Start the toolkit, called `KToolbar`.
2. Choose New Project from the toolbar to create a new project.

3. When the J2ME Wireless Toolkit asks you for the name of the project and the MIDlet class name, use "Jargoneer" for both.

4. Click the Create Project button, and then the OK button to dismiss the project settings window.

Figure 2-1 shows the New Project dialog box.

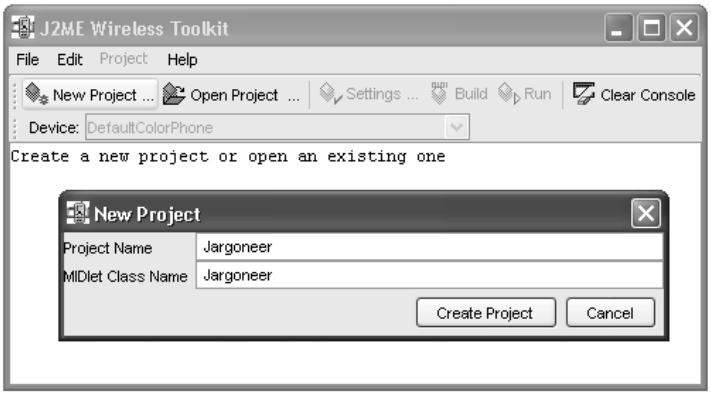

J2ME Wireless Toolkit
File Edit Project Help
New Project ... Open Project ... Settings ... Build Run Clear Console
Device: DefaultColorPhone
Create a new project or open an existing one
New Project
Project Name Jargoneer
MIDlet Class Name Jargoneer
Create Project Cancel

Figure 2-1. *Creating a new project with the J2ME Wireless Toolkit*

The J2ME Wireless Toolkit represents projects as subdirectories of its `apps` directory. The following shows the contents of the `Jargoneer` directory after the new project is created:

```
<J2ME Wireless Toolkit directory>
    apps
       Jargoneer
          bin
          lib
          res
          src
```

Save the source code as `Jargoneer.java` in the project's `src` directory. You can simply click the Build button in the J2ME Wireless Toolkit toolbar to compile the open project.

Behind the scenes, the J2ME Wireless Toolkit uses J2SE's compiler. Normally, when you're compiling J2SE source code, the `CLASSPATH` environment variable points to all the classes that your source code needs to know about. When you use `javac` to compile a file, there are some implied APIs that get included, like the classes in `java.lang`. With MIDlets, however, the situation is a little more complicated. Say that you use the `java.lang.System` class in your MIDlet. How do you (or how does the J2ME Wireless Toolkit) let the compiler know that you want to use the MIDP version of this class, not the J2SE version?

The answer is a command line option, `-bootclasspath`. This option lets you point to a classpath that describes the fundamental APIs against which you will be compiling your source code. In this case, this option should be used to specify the `classes` directory in the MIDP reference implementation installation. If you install the MIDP reference implementation, the command line looks like this:

```
javac -bootclasspath \midp\classes Jargoneer.java
```

You will need to adjust the path to `classes` if you installed the MIDP reference implementation in a different location.

Preverifying Class Files

Now comes an entirely new step in building your program, *preverifying*. Because the memory on small devices is so scarce, MIDP (actually, CLDC) specifies that bytecode verification be split into two pieces. Somewhere off the device, a preverify step is performed. The device itself is only required to do a lightweight second verification step before loading classes.

If you are using the J2ME Wireless Toolkit, you don't have to worry about preverifying class files, and you may not even notice that it's happening when you click the Build button. If you'd like to understand more about preverifying, read the rest of this section. Otherwise, you can just skip ahead.

As you may recall, bytecode verification is one of the foundation stones of Java's runtime security model. Before a classloader dynamically loads a class, the bytecode verifier checks the class file to make sure it behaves well and won't do nasty things to the JVM. Unfortunately, the code that implements the bytecode verifier is bulky, too large to fit on a small device like a mobile phone. The CLDC dictates a two-step bytecode verification:

1. Off the device, class files are preverified. Certain checks are performed, and the class file is massaged into a format that the lightweight second-step verifier can easily handle. This format is really just a regular class file, with some additional data attached by the preverifier.

2. On the device, the second step of verification is performed as classes are loaded. If a class file has not been preverified, it is rejected.

The MIDP reference implementation and the J2ME Wireless Toolkit contain a tool called `preverify` that performs the first step.

The `preverify` tools takes, as input, a class file. It produces a preverified class file. You need to specify a classpath so that the tool can find the class you want to preverify as well as any referenced classes. Finally, you can specify an output directory using the `-d` option. To overwrite an existing class file with a preverified version, you could do something like this:

```
preverify -classpath .;\ midp\ classes -d . Jargoneer
```

In this example, the `-d` option tells `preverify` to write the preverified class file to the current directory. Don't forget about inner classes, which must also be preverified.

■ **Note** Splitting bytecode verification into two pieces like this has important security ramifications. Devices should only download code from trusted sources, using a secure method because some bytecode verification is performed off the device. (See Chapter 3 for more information on MIDlet suite security.) An attacker could supply malicious code that appeared to be preverified, even if it violated the rules of the full J2SE bytecode verifier. To the MIDP second-step verifier, the code would look okay and it would be loaded and run.

Sun's J2ME Wireless Toolkit Emulators

The J2ME Wireless Toolkit includes several different emulators that you can use to test your applications. When you click the Run button in the J2ME Wireless Toolkit, your application is launched in the currently selected emulator.

The Wireless Toolkit Devices

The J2ME Wireless Toolkit 2.2 contains four main device emulators:

- `DefaultColorPhone` is a device with a 240×320-pixel color screen. This is the device shown later in Figure 2-2 and is used for most of the screen shots in the remainder of this book.
- `DefaultGrayPhone` has a 108×208 pixel grayscale screen.
- `MediaControlSkin` is similar to the default phone emulator and has a color screen of 108×208 pixels, but its buttons are labeled with controls like a music player: a square for stop, a triangle for play, volume control buttons, etc.
- `QwertyDevice` is a smartphone with a 636×235-color screen and a miniature QWERTY keyboard.

Running MIDlets

Sun's MIDP reference implementation includes an emulator named `midp`. It emulates an imaginary MID, a mobile telephone with some standard keys and a 182×210-pixel screen. The J2ME Wireless Toolkit includes a similar emulator, as well as several others.

Once you've got a preverified class file, you can use the `midp` emulator to run it. The emulator is an application that runs under J2SE and acts just like a MIDP device. It shows itself on your screen as a representative device, a generic mobile phone. You can run your MIDlet by typing the following at the command line, assuming you added `\midp\bin` to your `PATH`:

```
midp Jargoneer
```

If you're using the J2ME Wireless Toolkit, you can simply choose an emulator from the Device combo box and click the Run button to fire up your application.

If all goes well, you'll see something like the window shown in Figure 2-2 in the next section. Congratulations! You've just built and run your first MIDlet.

Using the Emulator Controls

The J2ME Wireless Toolkit emulator appears as a generic mobile phone, as shown in Figure 2-2.

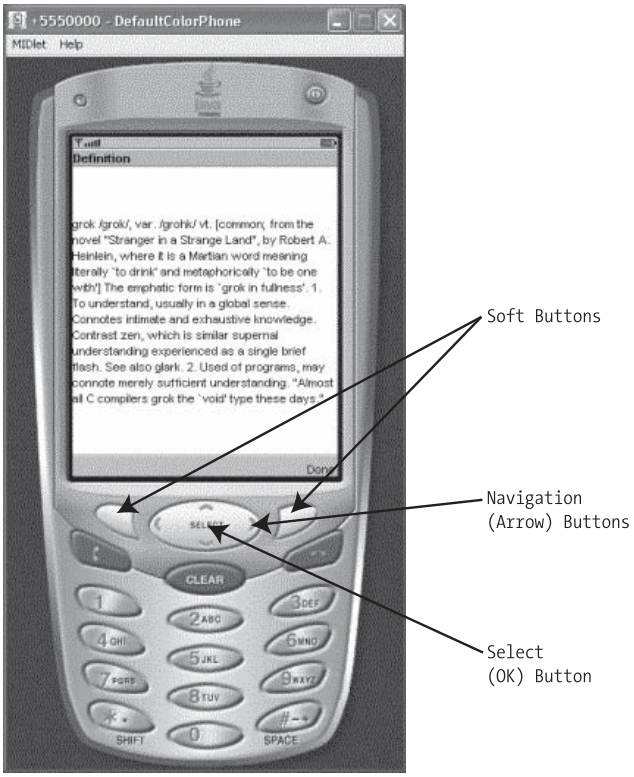

5550000 - DefaultColorPhone
MIDlet Help
Definition
grok /grok/, var. /grohk/ vt. [common; from the novel "Stranger in a Strange Land", by Robert A. Heinlein, where it is a Martian word meaning literally 'to drink' and metaphorically 'to be one with'] The emphatic form is 'grok in fullness'. 1. To understand, usually in a global sense. Connotes intimate and exhaustive knowledge. Contrast zen, which is similar supernal understanding experienced as a single brief flash. See also glark. 2. Used of programs, may connote merely sufficient understanding. "Almost all C compilers grok the 'void' type these days."
Done
SELECT
CLEAR
1
2 ABC
3 DEF
4 GHI
5 JKL
6 MNO
7 PQRS
8 TUV
9 WXYZ
*
0
#
SHIFT
SPACE
Soft Buttons
Navigation
(Arrow) Buttons
Select
(OK) Button

Figure 2-2. *Buttons on the J2ME Wireless Toolkit emulator*

SUN's J2ME Wireless Toolkit emulator exhibits several qualities that you are likely to find in real devices:

- The device has a small screen size and limited input capabilities. (It's not as small as the earlier J2ME Wireless Toolkit 1.x emulators, which included emulated devices with 96×128 and 96×54-pixel screens.)
- Two *soft buttons* are available. A soft button does not have a fixed function. Generally, the function of the button at any given time is shown on the screen near the button. In MIDlets, the soft buttons are used for commands.
- *Navigation buttons* are provided to allow the user to browse through lists or other sets of choices.
- A *select button* allows the user to make a choice after moving to it with the navigation buttons. (Think "Yes, that's my final answer.")

Tour of MIDP Features

Now that you have run your first MIDlet, take a moment to admire it. There are several salient features, even in such a small example.

It's Java

First of all, `Jargoneer` is written in the Java language, the same language you'd use to code servlets, Enterprise JavaBeans, or J2SE client applications. If you're already a J2SE developer, you should be quite comfortable developing MIDlets.

Not only is the Java language familiar, but also many core APIs are very similar to J2SE. Notice, for example, that multithreading in `Jargoneer` is just the same as it might be in any other Java code. The MIDlet class `Jargoneer` implements `java.lang.Runnable`, and the technique for kicking off a new thread is the same as it always was:

```
Thread t = new Thread(this);
t.start();
```

Significant parts of `java.lang` are essentially unchanged from J2SE, as are parts of `java.io` and `java.util`. The code that reads the result from the server in `lookUp()` is familiar stream handling, just like what you might see in J2SE.

MIDlet Life Cycle

`Jargoneer` also demonstrates the basic structure of MIDlets. Like all MIDlets, it extends `javax.microedition.midlet.MIDlet`, the base class for all MIDP applications. Special software on the device, called the Java Application Manager (JAM), Application Management Software (AMS), or MIDlet management software, allows the user to control the process of installing, running, and removing MIDlets. When a user chooses to run your MIDlet, it is the JAM that creates an instance of the MIDlet class and runs methods on it.

The sequence of methods that will be called in your MIDlet subclass is defined by the MIDlet life cycle. MIDlets, like applets and servlets, have a small set of well-defined states. The JAM will call methods in the MIDlet to signify transitions from one state to another. You can see these methods in `Jargoneer`—`startApp()`, `pauseApp()`, `destroyApp()`, and `Jargoneer`'s constructor are all part of the MIDlet life cycle.

Generalized User Interface

`Jargoneer`'s user-interface code may take you by surprise. Later on, we'll spend several chapters on user interface. For now, the important thing to notice is how `Jargoneer`'s user interface is flexible enough to run on devices with different screen sizes and different input capabilities. A big part of MIDP's appeal, after all, is the concept of writing one set of source code that runs on multiple devices.

One example of MIDP's generalized user interface is the `TextBox` that is initially shown when `Jargoneer` is launched. Figure 2-3 shows this `TextBox`.

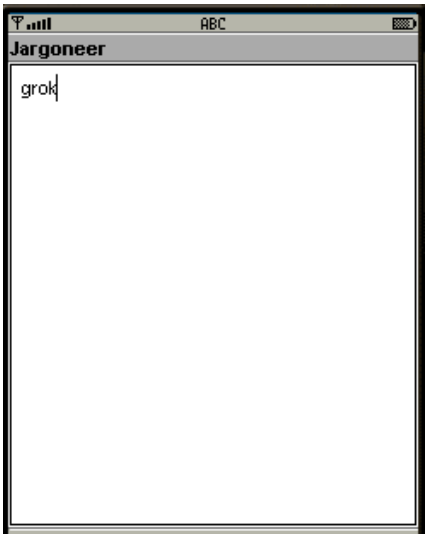


Figure 2-3. *Jargoneer's TextBox*

`TextBox` is a text input field. It has a title and an area for entering text. It has a simple design and can easily be shown on screens of different sizes. Even more interesting are the commands that appear at the bottom of the `TextBox`. These are `Exit` and `Find`. The code that creates the `TextBox` and its commands is in `Jargoneer`'s constructor:

```
mExitCommand = new Command("Exit", Command.EXIT, 0);
mFindCommand = new Command("Find", Command.SCREEN, 0);
// ...
mSubmitBox = new TextBox("Jargoneer", "", 32, 0);
mSubmitBox.addCommand(mExitCommand);
mSubmitBox.addCommand(mFindCommand);
mSubmitBox.setCommandListener(this);
```

Notice how the commands are created. You specify only a label and a type, and you register an event listener to find out when the commands are invoked. This is purposely vague—it leaves the implementation considerable latitude in deciding how commands should be displayed and invoked. In Sun's J2ME Wireless Toolkit emulator, for example, `TextBox` shows its commands at the bottom of the screen and allows the user to invoke them using soft buttons. Another device might put both commands in a menu and allow the user to invoke them using a selector wheel or some other mechanism. This is an example of the typical tradeoff between portability (the ability to run the application across multiple MIDP implementation) and precise control.

The Likelihood of Server-Side Components

The `Jargoneer` example connects to a web server, sends a request, and receives a response. The web server is actually an intermediary—it connects to the real Jargon File server, makes a request, parses the result, and sends the stripped-down definition back to the MIDP device.

In the first edition of this book, Jargoneer connected directly to the Jargon File server. In response to its query, it received a lot of information it didn't need. The original Jargoneer went to considerable trouble to parse through the HTML response to extract the definition it wanted. Architecturally, the old Jargoneer looked like Figure 2-4.

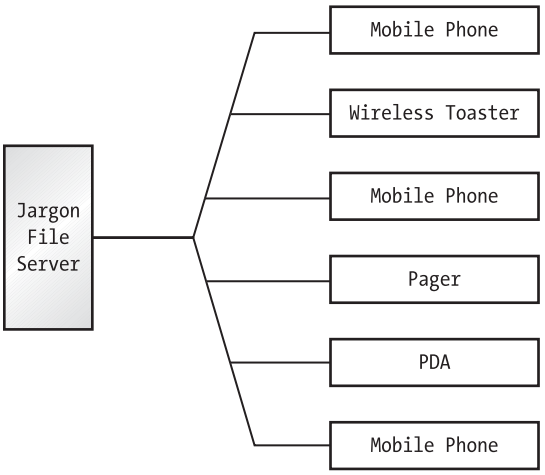


Figure 2-4. *Jargoneer architecture*

The new architecture is shown in Figure 2-5.

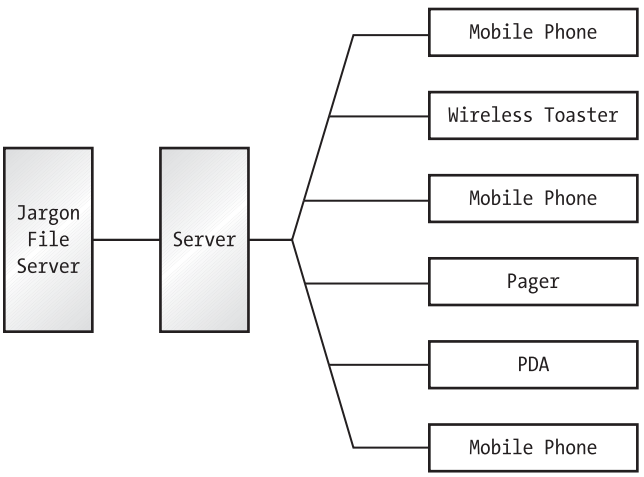


Figure 2-5. *A cleaner architecture for Jargoneer*

Instead of hitting the web server directly, Jargoneer goes through a different server hosted by Apress. This server queries the Jargon File, parses the result, and returns the definition to the device. This is advantageous from several standpoints:

- Bandwidth is expensive in terms of both time and money. Today's wireless networks are relatively slow, so less data passing through the air means less waiting time for your users. Also, wireless service tends to be pricey, so less data passing through the air means smaller bills for your users.
- Small devices have limited memory and processing power. It is unwise to spend these limited resources on tasks like parsing HTML. In general, you will be able to place most of the processing burden of your application on a server component, making your client MIDlet's life very easy.
- In this particular application, the HTML parsing is not very stable. Suppose the server we are using decides to return its Jargon File definitions in a different format; if four million users are running `Jargoneer`, then four million copies of our code have just broken. Performing this task on a server gives it a single point of failure and a single point of update. If we fix the parsing code on the server, the interface between the server and the client devices can remain unchanged. This makes it easy to upgrade or fix `Jargoneer`.

Network MIDP applications are likely to need a server component. If you're planning to do much MIDP development, you might like to study up on Java servlets.

Packaging Your Application

You won't pass class files directly to a MIDP to deploy an application. Instead, you'll package them in a Java Archive (JAR) using a packager such as the `jar` tool that comes with the Java 2 SDK.

If you're using the J2ME Wireless Toolkit, you won't ever have to perform these steps manually; the toolkit automatically packages your MIDlets when you choose Project ➤ Package ➤ Create Package from the menu. (You don't have to do this if you just want to test your application in the emulator, but you need to create a package if you're going to distribute the MIDlet suite.) Even if you use the J2ME Wireless Toolkit, you might want to read through this section so that you understand exactly what's going on.

If you're using the MIDP reference implementation, you should follow these steps to package your MIDlets. We'll only sketch the steps here; in the next chapter, you'll learn all the gory details of MIDlets and MIDlet suites.

Manifest Information

Every JAR includes a manifest file, `META-INF\MANIFEST.MF`, that describes the contents of the archive. For MIDlet JARs, the manifest file must contain extra information. The extra information is stuff that's important to the MIDP runtime environment, like the MIDlet's class name and the versions of CLDC and MIDP that the MIDlet expects.

You can specify extra manifest information in a simple text file and tell the `jar` utility to include that information in the manifest when the JAR is created. To package `Jargoneer`, for example, save the following text in a file named `extra.mf`:

```
MIDlet-1: Jargoneer, , Jargoneer
MIDlet-Name: Jargoneer
MIDlet-Vendor: Jonathan Knudsen
MIDlet-Version: 1.0
MicroEdition-Configuration: CLDC-1.0
MicroEdition-Profile: MIDP-2.0
```

Now assemble the MIDlet classes and the extra manifest information into a JAR with the following command:

```
jar cvmf extra.mf Jargoneer.jar Jargoneer.class
```

With the J2ME Wireless Toolkit, the toolkit automatically assembles your application into a MIDlet suite JAR when you click the Build button. It's very convenient, and it saves you from the effort of learning the `jar` tool.

Creating a MIDlet Descriptor

One additional file is needed before your MIDlet is ready to go out the door. An *application descriptor* file must be created. This file contains a lot of the same information that's in the MIDlet JAR manifest file. However, it lives outside the JAR and enables application management software to learn about a MIDlet JAR without installing it.

The application descriptor is a text file with a `.jad` extension. Type in the following and save it as `Jargoneer.jad`:

```
MIDlet-1: Jargoneer, , Jargoneer
MIDlet-Jar-Size: 2347
MIDlet-Jar-URL: Jargoneer.jar
MIDlet-Name: Jargoneer
MIDlet-Vendor: Jonathan Knudsen
MIDlet-Version: 1.0
MicroEdition-Configuration: CLDC-1.0
MicroEdition-Profile: MIDP-2.0
```

If your MIDlet suite JAR is a different size, enter the actual size for the `MIDlet-Jar-Size` entry. The MIDlet descriptor is automatically generated when you click the Build button in the J2ME Wireless Toolkit. If you're using the J2ME Wireless Toolkit, you won't need to create the application descriptor yourself.

Using an Obfuscator

Because MIDP devices have so little memory, MIDlet suites should be as compact as possible. An *obfuscator* is a useful tool for minimizing the size of MIDlet suite JARs. Obfuscators, originally designed to foil attempts to reverse engineer compiled bytecode, perform any combination of the following functions:

- Renaming classes, member variables, and methods to more compact names
- Removing unused classes, methods, and member variables
- Inserting illegal or questionable data to confuse decompilers

Except for the last point, obfuscators can significantly reduce the size of compiled classes in a MIDlet suite JAR.

There's a wide spectrum of obfuscators, with a variety of licenses, costs, and features. For a comprehensive list, see `http://proguard.sourceforge.net/alternatives.html`.

Using an obfuscator requires some finesse. The trick is to obfuscate the classes before they are preverified. The J2ME Wireless Toolkit includes support for inserting an obfuscator into the build cycle. Support for ProGuard is built in with version 2.2, and you can write adapter code to use other obfuscators. If you're using the 2.2 version of the toolkit, you just need to download ProGuard and copy the `proguard.jar` file into the toolkit's `bin` directory. Then choose Project ➤ Package ➤ Create Obfuscated Package and the toolkit handles all the details.

There is an article that describes how to use the ProGuard obfuscator with the J2ME Wireless Toolkit at `http://developers.sun.com/techtopics/mobility/midp/ttips/proguard/`.

The documentation that comes with the J2ME Wireless Toolkit includes a document called "J2ME Wireless Toolkit Basic Customization Guide." This guide describes how to add support for any obfuscator to the toolkit.

Obfuscators tend to be a little finicky, but once you get them configured correctly, they can provide significant size savings.

■ **Tip** You should not use the obfuscator during the regular coding/debug cycle, but just before packaging and deployment. This is because the obfuscator can often make debugging difficult.

Using Ant

Ant is a powerful build tool that is useful for automating MIDlet suite builds. It's similar in concept to `make`, but it is cleaner and easier to use. Ant is open source software, part of the Apache Jakarta project, at `http://ant.apache.org/`.

Ant is a tool for serious developers. If you believe you've exhausted the possibilities of the J2ME Wireless Toolkit, Ant is probably the next tool you should learn. Ant provides considerable flexibility in structuring your build cycle and lets you easily automate tasks like generating documentation or packaging source code. For an introduction to Ant and MIDP, see `http://developers.sun.com/techtopics/mobility/midp/articles/ant/`.

The code download for this book includes an Ant build script. A simplified version of the build script is shown in Listing 2-2.

Listing 2-2. *An Example Ant Build Script*

```
<project name="wj2" default="dist" basedir="..">
  <property name="project" value="wj2"/>

  <property name="midp" value="/WTK20"/>
  <property name="midp_lib" value="${midp}/lib/midpapi.zip"/>
```

```
  <target name="run">
    <exec executable="${midp}/bin/emulator">
      <arg line="-classpath build/bin/${project}.jar"/>
      <arg line="-Xdescriptor build/bin/${project}.jad"/>
    </exec>
  </target>

  <target name="dist" depends="preverify">
    <mkdir dir="build/bin"/>
    <jar basedir="build/preverified"
        jarfile="build/bin/${project}.jar"
        manifest="bin/MANIFEST.MF">
      <fileset dir="res"/>
    </jar>
    <copy file="bin/${project}.jad"
        tofile="build/bin/${project}.jad"/>
  </target>

  <target name="preverify" depends="obfuscate_null">
    <mkdir dir="build/preverified"/>
    <exec executable="${midp}/bin/preverify">
      <arg line="-classpath ${midp_lib}"/>
      <arg line="-d build/preverified"/>
      <arg line="build/obfuscated"/>
    </exec>
  </target>

  <target name="obfuscate_null" depends="compile">
    <mkdir dir="build/obfuscated"/>
    <copy todir="build/obfuscated">
      <fileset dir="build/classes"/>
    </copy>
  </target>

  <target name="compile" depends="init">
    <mkdir dir="build/classes"/>
    <javac destdir="build/classes" srcdir="src"
        bootclasspath="${midp_lib}" target="2.0"/>
  </target>

  <target name="init">
    <tstamp/>
  </target>
</project>
```

This build script contains targets that correspond to the steps of MIDlet suite development: `compile`, `preverify`, and `dist` (which packages the application). An `obfuscate_null` target is also included; it serves as a placeholder for inserting obfuscation in the build cycle. (The actual build script in the source download includes a target for obfuscating using ProGuard.)

Several developers have created specialized Ant tasks to help with MIDlet suite builds. One such project is here: `http://antenna.sourceforge.net/`.

Running on a Real Device

As of this writing, millions of MIDP-enabled phones are deployed worldwide. A comprehensive list of MIDP devices is available at `http://wireless.java.sun.com/device/`. How do you actually put MIDlets on a device? There are two possibilities: either you'll transfer MIDlet suites to the phone from your computer via an external connection (can be serial cable, USB cable, IRDA, Bluetooth, etc.—depending on the device manufacturer) , or you'll transfer MIDlet suites over the wireless network. This second possibility is called *over the air (OTA) provisioning*. There's a standard protocol for OTA, included with MIDP 2.0 specification. This protocol is available to MIDP 1.0 as an addendum to the specification.

Installing MIDlets via serial cable or OTA provisioning is specific to whatever device you're using. You'll have to check the documentation for your device to see exactly how to install MIDlet suites.

Summary

This chapter took you on a tour of MIDP development. Creating source code is much the same as in J2SE development, but the build process is different. First, the source code must be compiled against the MIDP classes using `javac`'s `-bootclasspath` option. Second, the class files must be preverified using the `preverify` command-line tool. With the J2ME Wireless Toolkit, these steps are conveniently automated. Just click the Build button to build and preverify. Applications can be easily tested in emulators using the J2ME Wireless Toolkit.

CHAPTER 3

All About MIDlets

In Chapter 2, you got a quick introduction to the process of building and running MIDlets. In this chapter, you'll explore the details. We'll cover the subjects that we skimmed in the last chapter, starting with the MIDlet life cycle and continuing through to a full discussion of MIDlet packaging. The chapter concludes with a look at the MIDlet security architecture.

The MIDlet Life Cycle

MIDP applications are represented by instances of the `javax.microedition.midlet.MIDlet` class. MIDlets have a specific life cycle, which is reflected in the methods and behavior of the `MIDlet` class.

A piece of device-specific software, the *application manager*, controls the installation, execution, and life cycle of MIDlets. MIDlets have no access to the application manager. A MIDlet is installed by moving its class files to a device. The class files will be packaged in a Java Archive (JAR), while an accompanying descriptor file (with a `.jad` extension) describes the contents of the JAR.

A MIDlet goes through the following states:

1. When the MIDlet is about to be run, an instance is created. The MIDlet's constructor is run, and the MIDlet is in the *Paused* state.
2. Next, the MIDlet enters the *Active* state after the application manager calls `startApp()`.
3. While the MIDlet is Active, the application manager can suspend its execution by calling `pauseApp()`. This puts the MIDlet back in the Paused state. A MIDlet can place itself in the Paused state by calling `notifyPaused()`.
4. While the MIDlet is in the Paused state, the application manager can call `startApp()` to put it back into the Active state.
5. The application manager can terminate the execution of the MIDlet by calling `destroyApp()`, at which point the MIDlet is *destroyed* and patiently awaits garbage collection. A MIDlet can destroy itself by calling `notifyDestroyed()`.

Figure 3-1 shows the states of a MIDlet and the transitions between them.

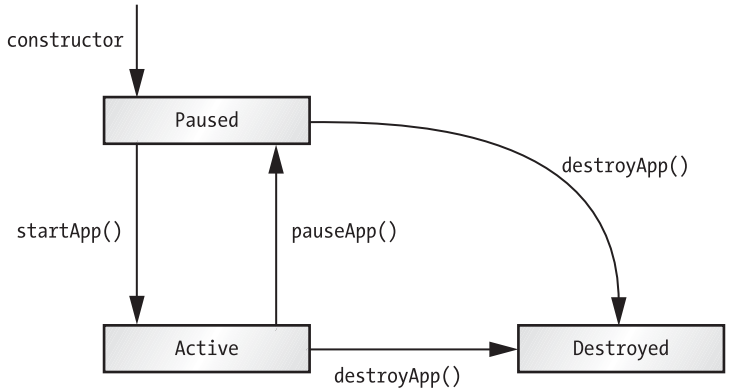


Figure 3-1. MIDlet life cycle

There is one additional method in the MIDlet class and it is related to the MIDlet life cycle: `resumeRequest()`. A MIDlet in the Paused state can call this method to signal to the application manager that it wants to become Active. It might seem weird to think about a MIDlet in the Paused state running any code at all. However, Paused MIDlets are still able to handle timer events or other types of callbacks and thus have some chances to call `resumeRequest()`. If the application manager does decide to move a MIDlet from the Paused to the Active state, it will do so through the normal mechanism of calling `startApp()`.

Requesting a Wakeup Call

MIDlets can request to be launched at a later time, in essence requesting a wakeup call from the implementation. The method is defined in `javax.microedition.io.PushRegistry`, which is kind of a weird place for it. All of `PushRegistry`'s other methods have to do with launching MIDlets in response to incoming network connections; the class is fully described in Chapter 10. The following method in `PushRegistry` requests that a named MIDlet be woken up at a specific time:

```
public static long registerAlarm(String midlet, long time)
    throws ClassNotFoundException, ConnectionNotFoundException
```

You need to supply the class name of a MIDlet in the MIDlet suite, and time specifies exactly when you want the MIDlet to be launched, in the standard form as the number of milliseconds since January 1, 1970. (Chapter 4 contains a discussion of MIDP's classes and methods pertaining to time.)

If you supply a class name that is not found in the current MIDlet suite, a `ClassNotFoundException` is thrown. If the implementation is unable to launch MIDlets at specified times, a `ConnectionNotFoundException` is thrown.

If the MIDlet for which you are requesting a timed launch was previously registered for timed launch, this method returns the previous wakeup time.

A Bridge to the Outside World

Many MIDP devices, especially mobile phones, have web browsers, using either the WAP or HTTP protocol. The `MIDlet` class supplies a bridge to these browsers and other capabilities:

```
public final boolean platformRequest(String URL)
    throws ConnectionNotFoundException
```

On a sophisticated device, the browser and the MIDlet suite may be able to run at the same time, in which case the browser will be launched and pointed to the specified URL. In this case, the method returns true.

On smaller devices, the browser may not be able to run until the MIDlet is destroyed. In this case, `platformRequest()` returns false, and it's the MIDlet's responsibility to terminate. After the MIDlet terminates, it's the implementation's responsibility to launch the browser and point it at the specified URL.

In either case, `platformRequest()` is a nonblocking method.

There are two special possibilities for the supplied URL. If you supply a telephone number URL of the form tel:<number> as specified in RFC 2806 (`http://ietf.org/rfc/rfc2806.txt`), the implementation should initiate a voice call.

If you supply the URL of a MIDlet suite descriptor or JAR, the implementation should eventually start the application manager and attempt to install the given MIDlet suite (after asking for your permission, of course).

Packaging MIDlets

MIDlets are deployed in *MIDlet suites*. A MIDlet suite is a collection of MIDlets with some extra information. There are two files involved. One is an *application descriptor*, which is a simple text file. The other is a JAR file that contains the class files and resource files that make up your MIDlet suite. Like any JAR file, a MIDlet suite's JAR file has a manifest file. Figure 3-2 shows a diagram of a MIDlet suite.

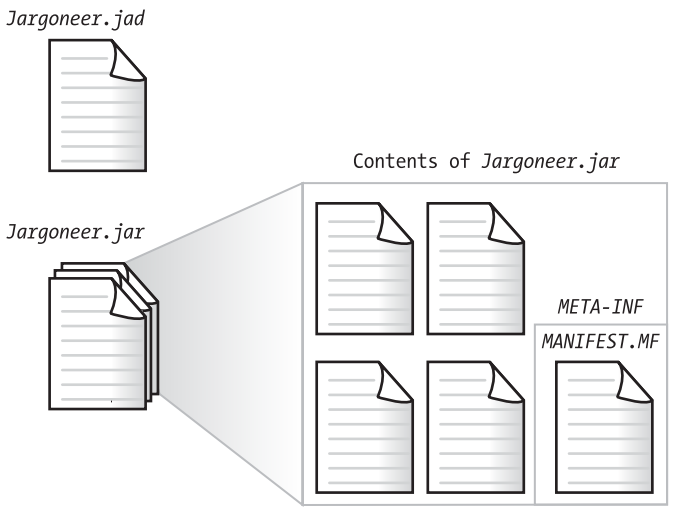


Figure 3-2. Antatomy of a MIDlet suite

If you are using a tool like the J2ME Wireless Toolkit, you don't need to worry much about MIDlet suite packaging because most of the details are handled automatically. If you want to understand things at a lower level, or if you're just curious, keep reading for a complete description of MIDlet suite packaging.

Packaging a MIDlet suite consists of three steps:

1. The class files and resource files that make up the MIDlets are packaged into a JAR file. Usually, you'll use the `jar` command-line tool to accomplish this.
2. Additional information that's needed at runtime is placed in the JAR's manifest file. All JARs include a manifest; a MIDlet suite JAR contains some extra information needed by application management software.
3. An application descriptor file should also be generated. This is a file with a `.jad` extension that describes the MIDlet suite JAR. It can be used by the application management software to decide whether a MIDlet suite JAR should be downloaded to the device.

MIDlet Manifest Information

The information stored in a MIDlet's manifest file consists of name and value pairs, like a properties file. For example, an unadorned JAR manifest might look like this:

```
Manifest-Version: 1.0
Created-By: 1.4.2_04 (Sun Microsystems Inc.)
```

A MIDlet JAR manifest for `Jargoneer` looks like this:

```
Manifest-Version: 1.0
MIDlet-1: Jargoneer, Jargoneer.png, Jargoneer
MIDlet-Name: Jargoneer
MIDlet-Version: 2.0
MIDlet-Vendor: Sun Microsystems
Created-By: 1.4.2_04 (Sun Microsystems Inc.)
MicroEdition-Configuration: CLDC-1.0
MicroEdition-Profile: MIDP-2.0
```

The extra attributes describe software versions, class names, and other information about the MIDlet suite. The following attributes must be included:

- `MIDlet-Name`: Despite the moniker, this attribute actually refers to the name of the entire MIDlet suite, not just one MIDlet.
- `MIDlet-Version`: This describes the version of the MIDlet suite. It's a number you pick yourself in the form `major.minor.micro`.
- `MIDlet-Vendor`: This is your name or the name of your company.
- `MIDlet-n`: For each MIDlet in the MIDlet suite, the displayable name, icon file name, and class name are listed. The MIDlets must be numbered starting from 1 and counting up. For example, several MIDlets in a single MIDlet suite could be listed like this:

```
MIDlet-1: Sokoban, /icons/Sokoban.png, example.sokoban.Sokoban
MIDlet-2: Tickets, /icons/Auction.png, example.lcdui.TicketAuction
MIDlet-3: Colors, /icons/ColorChooser.png, example.chooser.Color
MIDlet-4: Stock, /icons/Stock.png, example.stock.StockMIDlet
```

- `MicroEdition-Configuration`: This attribute describes the J2ME configurations upon which this MIDlet suite can run. Multiple configuration names should be separated by spaces.
- `MicroEdition-Profile`: This describes the set of profiles upon which this MIDlet suite can run. For MIDP 2.0 applications, this is `MIDP-20`. For applications that can also run on the older MIDP 1.0 profile, use "MIDP-2.0 MIDP-1.0".

In addition to the required manifest attributes, the following attributes may be defined:

- `MIDlet-Description`: The description of the MIDlet suite goes in this attribute.
- `MIDlet-Icon`: Icons for individual MIDlets are described in the `MIDlet-n` attributes. This attribute specifies an icon to represent the entire MIDlet suite.
- `MIDlet-Info-URL`: If additional information about the MIDlet suite is available online, use this attribute to list the URL.
- `MIDlet-Data-Size`: If you know how many bytes of persistent data are required by the MIDlet suite, you can specify the number with this attribute.

■ **Tip** Don't get tripped up by the attribute names. Many of them appear to refer to a single MIDlet, like `MIDlet-Name` and `MIDlet-Description`. In fact, these attributes describe an entire MIDlet suite. The only attribute that applies to a specific MIDlet is the `MIDlet-n` attribute, which is used to list each MIDlet in the suite.

Several additional attributes may be included. Network APIs can be protected from unauthorized access using a permission scheme, which will be fully discussed later in this chapter. MIDlets can list necessary permissions and optional permissions in the MIDlet JAR manifest as follows:

- `MIDlet-Permissions`: Use this attribute to list permissions that are critical to the operation of the MIDlet suite. Multiple permissions are separated by commas.
- `MIDlet-Permissions-Opt`: This attribute lists permissions that may be used but are not critical for this MIDlet suite.

Finally, there is also a way for MIDlet suites to signal their dependence on optional APIs:

- `MIDlet-Extensions`: List the required Optional APIs used by this MIDlet suite in this attribute. The exact names are determined by the individual optional API specifications.

Application Descriptor

The attributes in a MIDlet suite JAR are used by the application management software to run MIDlets within a suite. The application descriptor, by contrast, contains information that helps a device and/or the user decide whether or not to load a MIDlet suite. Because an application descriptor is a file separate from the MIDlet suite JAR, it is easy for a device to load and examine the file before downloading the MIDlet suite.

As it happens, a lot of the information in the application descriptor has to be the same as the information that's in the MIDlet suite JAR. For example, the application descriptor must contain the `MIDlet-Name`, `MIDlet-Version`, and `MIDlet-Vendor` attributes. In addition, it must include the following:

- `MIDlet-Jar-URL`: This is the URL where the MIDlet suite JAR can be found.
- `MIDlet-Jar-Size`: This is the size, in bytes, of the MIDlet suite JAR.

The application descriptor can optionally contain the `MIDlet-Description`, `MIDlet-Icon`, `MIDlet-Info-URL`, and `MIDlet-Data-Size` attributes.

Devices and emulators vary widely in their handling of MIDlet suite descriptors. Some will fail installation if any fields in the descriptor are incorrect, while others are more lenient. A tool like the J2ME Wireless Toolkit is extremely useful in creating well-formed descriptors.

The application descriptor is useful in over the air (OTA) deployment. A device (and the user) can download and inspect the descriptor, a relatively short file, before deciding whether the entire MIDlet suite JAR should be downloaded and installed. For OTA provisioning, the server's returned MIME type for the application descriptor should be `text/vnd.sun.j2me.app-descriptor`. This and more (a whole protocol) is described in the "Over the Air User Initiated Provisioning Specification" section of the MIDP 2.0 specification.

MIDlet Properties

There's one other possibility for attributes in the manifest or application descriptor. You can add attributes that have meaning to your MIDlets. MIDlets can retrieve the values of these attributes using the `getAppProperty()` method in the `javax.microedition.midlet.MIDlet` class. An attribute can be listed in the application descriptor, JAR manifest, or both; if it is listed in both, the value from the application descriptor will be used. In general, it makes sense to store application properties in the application descriptor file. Because it's distinct from the MIDlet suite JAR, the application descriptor can easily be changed to modify the behavior of your MIDlets. You might, for example, store a URL or other configuration information in the application descriptor.

For example, suppose you put an application-specific attribute in the application descriptor, like this:

```
Jargoneer.url: http://www.dict.org/bin/Dict
```

Inside the MIDlet, you can retrieve the value of the attribute like this:

```
String url = getAppProperty("Jargoneer.url");
```

Changing the URL is as easy as changing the application descriptor, a simple text file. None of your code needs to be recompiled. This could be useful if you were expecting to distribute many copies of a MIDlet and wanted to share the server load among a group of servers. You could distribute the same MIDlet suite JAR with a group of different application descriptors, each one using a MIDlet attribute to point to a different server.

MIDlet Suite Security

Wireless application security is important to almost everyone involved in the wireless industry:

- Carriers want to be sure that viruses do not bring down their customers' devices or their networks.
- Device manufacturers don't want customer-installed software crashing their devices.
- Users want to be able to run downloaded code without threatening the stability of their device or the safety of their personal information. Additionally, they may want control over the network usage of their applications, as network usage often costs money.
- Application developers do not want their applications to be compromised by other applications.

Permissions

Permissions provide MIDlets with an explicit security architecture. In a nutshell, MIDlets must have *permission* to perform sensitive operations. The only parts of the API that are protected by permissions are the network connections. Optional APIs are free to define additional permissions to protect sensitive data or functionality.

Permission names use the same prefix and class or interface name as the API that they protect. In Chapter 10, we'll explain the names of the network permissions in detail. For the moment, suppose that you write a MIDlet that needs to make a socket connection. This MIDlet would need the permission of `javax.microedition.io.Connector.socket`. The MIDlet itself needs no knowledge of permissions. It simply attempts the connection, which either succeeds or throws a `java.lang.SecurityException`.

There is a method in the `MIDlet` class that programmers can use to check if a permission will be granted or denied:

```
public final int checkPermission(String permission)
```

This method returns 1 if the permission is granted and 0 if the permission is denied. A special return value, `-1`, indicates that the implementation cannot determine whether the permission will be granted or denied, which might be the case if the user will be asked about the given permission.

Protection Domains

MIDlet suites belong to *protection domains* that determine which permissions are granted, which are denied, and which ones must be deferred to the user's judgment. A protection domain is kind of like a secret club and comprises two parts:

1. The set of permissions that are allowed and those for which the user must be consulted
2. The rules for how a MIDlet suite can get into this protection domain

A very simple protection domain, "SimplePD," might contain the permission `javax.microedition.io.Connector.http`. The rules for membership in SimplePD could be something as simple as verifying the origin IP address of the MIDlet suite. For example, if the MIDlet suite is downloaded from `www.bigcarrier.com`, then the application management software on the device would know to place the MIDlet suite in the SimplePD protection domain. At runtime, any MIDlet that tries to make an HTTP connection will be granted the permission. Attempts to make other connection types will be denied.

The simple IP-origin criterion for SimplePD is pretty weak. MIDlet suites in SimplePD are susceptible to many attacks, including data modification, data replacement, man-in-the-middle attacks, and DNS spoofing. More robust rules are based on cryptographic solutions for data integrity and authentication. In the MIDP 2.0 specification, the section "Trusted MIDlet Suites Using X.509 PKI" describes one such scheme, including additional manifest attributes.

MIDlet suites whose contents and origin cannot be verified are placed in a kind of default protection domain, the *untrusted* domain. The only restriction placed on the untrusted domain is that, given explicit confirmation from the user, it must allow MIDlets access to HTTP and HTTPS connections.

The concept of protection domains is deliberately vague, leaving MIDP vendors with considerable latitude in their implementation. Our guess is that many implementations will choose to have a single untrusted domain and a single trusted domain, with entry to the trusted domain limited to cryptographically signed (and verified) MIDlet suites.

Permission Types

The protection domain contains the permissions that will be granted to MIDlets (*allowed* permissions) as well as the permissions for which the user must be consulted (*user* permissions). There are several varieties of user permissions. *Blanket* means that the user is only required to grant or deny the permission once for a MIDlet suite. *Session* means that the user must grant or deny permission once per invocation of a MIDlet suite. Finally, *oneshot* indicates that the user must be consulted each time the necessary permission is needed.

Permissions in MIDlet Suite Descriptors

There are additional attributes for MIDlet suite descriptors. If your MIDlet suite absolutely, positively needs certain permissions, use the `MIDlet-Permissions` attribute. For example, if your MIDlet suite needs to make HTTP connections to function correctly, you would have a line in your descriptor file like this:

```
MIDlet-Permissions: javax.microedition.io.Connector.http
```

Multiple permission types are placed on the same line, separated by commas.

If your MIDlet suite does not need certain permissions to function, but it may use them for enhanced functionality, these permissions can be placed in the `MIDlet-Permissions-Opt` attribute.

At installation time, the application management software will compare the permissions requested in the descriptor with the permissions in the destination protection domain. If there are irreconcilable differences, the MIDlet suite will not be installed.

Summary

MIDP applications are called MIDlets. Like applets or servlets, MIDlets have a specific life cycle; they are managed by device software. This chapter detailed the entries that must and may be in the MIDlet suite manifest file and the application descriptor. Application properties can be used as a way to store information in the application descriptor instead of hard-coding values into the MIDlet source code. A tool like the J2ME Wireless Toolkit automatically handles many of the details of MIDlet attributes packaging. MIDlets enjoy a comprehensive security architecture based on protection domains.

CHAPTER 4

Almost the Same Old Stuff

As we discussed in Chapter 1, one of the reasons you might be interested in MIDP as a platform is that it's based on the Java programming language and the Java APIs. You'll also recall that MIDP is built on top of the Connected, Limited Device Configuration (CLDC). The CLDC contains most of the APIs that will look familiar to experienced Java programmers. As of this writing, CLDC 1.0 is the most widely available version, but many newer devices are beginning to support the CLDC 1.1 specification. We'll mention the differences between CLDC 1.0 and CLDC 1.1 throughout this chapter.

In this chapter, we'll explore the `java.lang`, `java.io`, and `java.util` packages as defined in the CLDC. We'll assume you're already familiar with the basic APIs of J2SE; we'll walk through what's the same and what's different.

At the time of this writing (first quarter 2005), CLDC 1.1 and MIDP 2.0 have been implemented on real devices from several manufacturers (Nokia, Siemens, Sony Ericsson, just to name a few). The industry-wide endorsement of the JTWI (JSR 185) has prompted the rapid adoption of MIDP 2.0. Although some JTWI devices only implement MIDP 2.0 over CLDC 1.0, it is anticipated most new devices will be implemented on top of CLDC 1.1.

No Floating Point in CLDC 1.0

CLDC 1.0 does not support floating-point types at all. That means there are no `float` or `double` primitive types. The corresponding wrapper types, `java.lang.Float` and `java.lang.Double`, have also been eliminated.

Floating-point support is absent in CLDC 1.0. On CLDC 1.0 devices, if calculations involving fractional numbers are important to your application, you can perform them in software. One implementation (using fixed-point integers) can be found at `http://home.rochester.rr.com/ohommes/MathFP/`.

CLDC 1.1 includes floating-point support, the primitive types `double` and `float`, and the wrapper types `Double` and `Float`. Various other classes have been modified for floating-point support in CLDC 1.1, but the changes are minor.

java.lang

Table 4-1 and Table 4-2 list the classes and interfaces of `java.lang` and `java.lang.ref` in both J2SE (SDK version 1.4.2) and CLDC. The CLDC columns indicate whether the class is identical to its J2SE counterpart, is present with API differences, or is not present at all.

Table 4-1. *The java.lang Package*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
Interfaces		
CharSequence	–	–
Cloneable	–	–
Comparable	–	–
Runnable	Same	Same
Classes		
J2SE SDK 1.4.2	**CLDC 1.0**	**CLDC 1.1**
Boolean	Different	Different
Byte	Different	Same as CLDC 1.0
Character	Different	Same as CLDC 1.0
Character.Subset	–	–
Character.UnicodeBlock	–	–
Class	Different	Same as CLDC 1.0
ClassLoader	–	–
Compiler	–	–
Double	–	Different
Float	–	Different
InheritableThreadLocal	–	–
Integer	Different	Different
Long	Different	Different
Math	Different	Different
Number	–	–
Object	Different	Same as CLDC 1.0
Package	–	–
Process	–	–
Runtime	Different	Same as CLDC 1.0
RuntimePermission	–	–
SecurityManager	–	–
Short	Different	Same as CLDC 1.0
StackTraceElement	–	–
StrictMath	–	–

Table 4-1. *The java.lang Package (Continued)*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
`String`	Different	Different
`StringBuffer`	Different	Different
`System`	Different	Same as CLDC 1.0
`Thread`	Different	Different
`ThreadGroup`	–	–
`ThreadLocal`	–	–
`Throwable`	Different	Same as CLDC 1.0
`Void`	–	–

Table 4-2. *The java.lang.ref Package*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
Classes		
`PhantomReference`	–	–
`Reference`	–	Different
`ReferenceQueue`	–	–
`SoftReference`	–	–
`WeakReference`	–	Different

`java.lang.Object`, as always, is the root of every Java class. It remains mostly unchanged from J2SE, but there are some important differences. These differences are detailed in the upcoming text.

No Object Finalization

Object finalization is not available in CLDC (and, by extension, MIDP). Finalization is a mechanism by which objects can clean up after themselves just before they are garbage collected. In J2SE, an `Object`'s `finalize()` method is called before the object is reclaimed by the garbage collector. No such mechanism exists in CLDC. If you need to clean up resources, you will need to do it explicitly instead of placing cleanup code in `finalize()`. This is a good idea anyhow, particularly in a small device with limited resources. Explicitly cleaning up resources means that the memory and processing power they consume will be reclaimed sooner rather than later. Cleanup code in `finalize()` methods doesn't get executed until the garbage collector runs, and you never know exactly when that's going to happen.

■ **Tip** On the topic of cleaning up after yourself, it is always a good idea when programming in a small platform such as MIDP to set any object references to null as soon as you finish using them. Doing so will help the garbage collector to perform its job.

No Reflection

CLDC does not support the Reflection API. The target devices of CLDC/MIDP are simply too small to allow it. Although most developers don't need to use reflection directly, this omission has important implications. Without reflection, no Remote Method Invocation (RMI) is possible. Without RMI, JINI is not possible. Therefore, bare-bones CLDC/MIDP implementations cannot run JINI. If you want to run JINI, you'll need to investigate one of the larger J2ME profiles, most likely the Personal Profile (see Chapter 1) and the RMI Optional API (JSR 66).

No Native Methods

Native methods are not supported in CLDC (and, by extension, MIDP). The specification does not support a way to access native device methods from Java. Although the MIDP implementation does, of course, include native methods, they are compiled into the implementation itself. Applications cannot define new native methods.

Don't worry about losing access to platform-specific features, however, because device vendors are likely to implement proprietary APIs in addition to MIDP. For details, check the developer web site of the manufacturer or network carrier of your device. Bear in mind that your use of vendor- or device-specific APIs will limit the audience of your application. In certain instances (games, for example), it makes sense to distribute multiple versions of an application targeted at specific devices.

No User Classloading

As we discussed in Chapter 1, one of the strengths of the Java platform is the ability to load classes at runtime. Unfortunately, because of resource constraints and security concerns, CLDC does not allow you to define your own classloaders. The application manager that runs MIDlets has a classloader, but you cannot access it or use it yourself in any way.

Multithreading

Using threads is much as you remember it from J2SE, as long as you keep things simple. Creating new threads, starting them, and using the handy `java.lang.Runnable` interface are the same as in J2SE. One important omission in CLDC 1.0 is the `interrupt()` method, which is not present in the `java.lang.Thread` class. In CLDC 1.1, the `interrupt()` method is available.

The `pause()`, `resume()`, and `stop()` methods (which are deprecated in the J2SE SDK) are also absent. Thread groups and daemon threads are not supported in CLDC/MIDP; thread naming is not supported in CLDC 1.0 but is available in CLDC 1.1.

String and StringBuffer

Both `String` and `StringBuffer` are present in the CLDC `java.lang` package. They are largely unchanged from their J2SE counterparts.

The largest change in the `String` class in CLDC 1.0 is the elimination of `valueOf()` static methods that convert between floating-point primitives and `String`s, although these are present in CLDC 1.1. A few other obscure methods are absent from CLDC's `String` class, but you probably won't miss them. For example, although CLDC's `String` includes the `compareTo(String str)` method, it doesn't have either the `compareTo(Object o)` or `compareToIgnoreCase(String str)` methods that are found in the J2SE SDK. (CLDC 1.1 does include an `equalsIgnoreCase()` method in the `String` class.) There are simple workarounds for these limitations. You can, for example, call the `toString()` method on an object and pass it to `compareTo(String str)`.

`StringBuffer`'s `append()` and `insert()` methods do not include overrides for floating-point types in the CLDC 1.0 version of the class, but these are available in CDLC 1.1. Also, the `substring()` method has been pruned. Other than that, however, `StringBuffer` should be very familiar for seasoned J2SE programmers.

Math

The `Math` class contains static methods for performing mathematical calculations. In J2SE, many of these methods involve trigonometric functions on floating-point numbers. In CLDC 1.0, these are all gone, leaving only a handful of methods. CLDC 1.1, because it supports floating-point types, includes several more methods in `java.lang.Math`, but CLDC's `java.lang.Math` is still a subset of the J2SE version of the class. In the API listing that follows, the plus signs (+) indicate new variables or methods in CLDC 1.1.

```
  public final class Math
      extends java.lang.Object {
    // Constants
+   public static final double E;
+   public static final double PI;
      // Static methods
    public static int abs(int a);
    public static long abs(long a);
+   public static float abs(float a);
+   public static double abs(double a);
+   public static native double ceil(double a);
+   public static native double cos(double a);
+   public static native double floor(double a);
    public static int max(int a, int b);
    public static long max(long a, long b);
+   public static float max(float a, float b);
+   public static double max(double a, double b);
    public static int min(int a, int b);
    public static long min(long a, long b);
+   public static float min(float a, float b);
+   public static double min(double a, double b);
+   public static native double sin(double a);
```

```
+   public static native double sqrt(double a);
+   public static native double tan(double a);
+   public static double toDegrees(double angrad);
+   public static double toRadians(double angdeg);
  }
```

Runtime and System

`Runtime` and `System` provide access to the Java Virtual Machine (JVM) and system-wide resources. These two classes are greatly reduced from their J2SE counterparts, so much so that it makes sense to reproduce their entire public API here. First, let's take a look at `Runtime`:

```
public class Runtime
    extends java.lang.Object {
  // Static methods
  public static Runtime getRuntime();

 // Methods
  public void exit(int status);
  public  long freeMemory();
  public  void gc();
  public  long totalMemory();
}
```

To get the single `Runtime` instance, call `getRuntime()`. You can tell the JVM to run its garbage collector by calling `gc()`. On MIDP, if you try to call `exit()`, a `SecurityException` will be thrown; the application life cycle is managed entirely through the methods of the MIDlet class. The other two methods, `totalMemory()` and `freeMemory()`, allow you to examine the amount of memory that is available for your application's data.

Note that `Runtime` does not support running external processes with the `exec()` method. MIDlets cannot step outside the bounds of the JVM.

`System` provides static methods for performing various common tasks:

```
public final class System
    extends java.lang.Object {
  // Constants
  public static final PrintStream err;
  public static final PrintStream out;

  // Static methods
  public static  void arraycopy(Object src, int src_position,
      Object dst, int dst_position, int length);
  public static  long currentTimeMillis();
  public static void exit(int status);
  public static void gc();
  public static String getProperty(String key);
  public static  int identityHashCode(Object x);
}
```

The first thing you might notice is that while the `err` and `out` `PrintStreams` are defined, there is no `System.in`. This makes sense—`System.in` represents the console input; on a MIDP device, there really isn't any console. In fact, it may seem weird to have `System.out` and `System.err` defined. If you print information to `System.out`, it may not come out anywhere on a device; however, on a device emulator, you may be able to view `System.out` in a console window. Of course, any code that contains output to `System.out` and `System.err` should be removed from production code.

The `gc()` and `exit()` methods are shortcuts for calling the corresponding methods in the `Runtime` class.

All of `System`'s methods are static. The `arraycopy()` method provides a fast implementation of array copying.

Finally, `identityHashCode()` is a default used by `Object`'s `hashCode()` method.

The `getProperty()` method returns system properties, which are different from the MIDlet properties returned by MIDlet's `getAppProperty()` method. The following standard system properties are supported and their values can be retrieved at runtime:

- `microedition.platform`: This property contains the name of the device or host platform. If the implementation does not supply a value, the default is null.
- `microedition.encoding`: This property contains the default character encoding, which specifies how Unicode characters are represented in a byte stream, for example, "ISO-8859-1".
- `microedition.configuration`: This property contains the name of the implemented configuration, for example, "CLDC-1.1".
- `microedition.profiles`: Implemented profiles are contained in this system property, for example, "MIDP-2.0".

Streams in java.io

The `java.io` package in the CLDC/MIDP world is a stripped-down version of `java.io` in J2SE. Table 4-3 summarizes the classes of `java.io` in both J2SE and CLDC/MIDP. As you can see, many of the `java.io` classes you normally find in J2SE are missing from CLDC/MIDP.

Table 4-3. *The java.io Package*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
Interfaces		
`DataInput`	Different	Different
`DataOutput`	Different	Different
`Externalizable`	–	–
`FileFilter`	–	–
`FilenameFilter`	–	–
`ObjectInput`	–	–
`ObjectInputValidation`	–	–

Table 4-3. *The java.io Package (Continued)*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
ObjectOutput	–	–
ObjectStreamConstants	–	–
Serializable	–	–
Classes		
J2SE SDK 1.4.2	**CLDC 1.0**	**CLDC 1.1**
BufferedInputStream	–	–
BufferedOutputStream	–	–
BufferedReader	–	–
BufferedWriter	–	–
ByteArrayInputStream	Same	Same
ByteArrayOutputStream	Different	Same as CLDC 1.0
CharArrayReader	–	–
CharArrayWriter	–	–
DataInputStream	Different	Different
DataOutputStream	Different	Different
File	–	–
FileDescriptor	–	–
FileInputStream	–	–
FileOutputStream	–	–
FilePermission	–	–
FileReader	–	–
FileWriter	–	–
FilterInputStream	–	–
FilterOutputStream	–	–
FilterReader	–	–
FilterWriter	–	–
InputStream	Same	Same
InputStreamReader	Different	Same as CLDC 1.0

Table 4-3. *The java.io Package (Continued)*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
LineNumberInputStream	–	–
LineNumberReader	–	–
ObjectInputStream	–	–
ObjectInputStream.GetField	–	–
ObjectOutputStream	–	–
ObjectOutputStream.PutField	–	–
ObjectStreamClass	–	–
ObjectStreamField	–	–
OutputStream	Same	Same
OutputStreamWriter	Different	Same as CLDC 1.0
PipedInputStream	–	–
PipedOutputStream	–	–
PipedReader	–	–
PipedWriter	–	–
PrintStream	Different	Different
PrintWriter	–	–
PushbackInputStream	–	–
PushbackReader	–	–
RandomAccessFile	–	–
Reader	Same	Same
SequenceInputStream	–	–
SerializablePermission	–	–
StreamTokenizer	–	–
StringBufferInputStream	–	–
StringReader	–	–
StringWriter	–	–
Writer	Same	Same

Although the differences between the J2SE and CLDC classes appear large, they can be easily grouped into three categories:

1. Because CLDC/MIDP by itself has no concept of a local file system, all the classes having to do with files have been pruned from the `java.io` package. This includes `File`, `FileInputStream`, `FileOutputStream`, the corresponding `Reader` and `Writer` classes, `RandomAccessFile`, and various supporting classes. If you need to store data persistently on a device, you'll need to use the `javax.microedition.rms` package API, described in Chapter 8. Some devices may expose a file system through an optional API: the File Connection Optional Package (JSR 75). In addition, devices that act as a Personal Information Manager (PIM) can also provide access to its persistent data through the optional PIM APIs (also part of JSR 75). These optional APIs are described in Chapter 9.

2. Object serialization is not supported in CLDC. This means that the `Serializable` interface and various object stream classes are not present.

3. Finally, J2SE includes a handful of utility stream classes—things you might want someday but shouldn't include on a device with a small amount of memory. These classes include piped streams, pushback streams, sequence streams, line numbering streams, and a few other gems like `StreamTokenizer`. If you really need one of these in your MIDlet, you may be able to package it with your application.[1] Bear in mind that there are licensing restrictions and technical problems with using classes directly from J2SE; be sure you understand the legal implications before you start copying files.

Character Encodings

MIDP includes the `Reader` and `Writer` character streams for working with Unicode characters. `InputStreamReader` and `OutputStreamWriter` handle the conversion between byte streams and character streams, just as in J2SE. An `encoding` determines how translation occurs between byte streams and character streams. A default encoding is used if you don't specify one. You can pass an encoding name to the constructors for `InputStreamReader` and `OutputStreamWriter`, if you wish. So far, this is all the same as in J2SE. In MIDP, though, you will likely find many fewer available encodings than in J2SE.

The default encoding for a MIDP implementation can be obtained by calling `System.getProperty("microedition.encoding")`—for example, ISO8859-1.

Resource Files

As described in Chapter 8, you can retrieve resource files from your MIDlet suite's JAR file. Use the `getResourceAsStream()` method in `Class`; it returns an `InputStream` that you can use as you please.

1. A better idea would be to redesign your application so that complicated stream processing isn't necessary on the device. In general, you should make your server do as much work as possible and your MIDlet do as little as possible.

java.util

CLDC includes only a dozen classes from J2SE's `java.util` package. Many of the missing classes are part of the Collections API, which is too bulky for small devices. Table 4-4 lists the classes and interfaces of `java.util` in both J2SE and CLDC/MIDP.

Table 4-4. *The java.util Package*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
Interfaces		
`Collection`	–	–
`Comparator`	–	–
`Enumeration`	Same	Same
`EventListener`	–	–
`Iterator`	–	–
`List`	–	–
`ListIterator`	–	–
`Map`	–	–
`Map.Entry`	–	–
`Observer`	–	–
`RandomAccess`	–	–
`Set`	–	–
`SortedMap`	–	–
`SortedSet`	–	–
Classes		
J2SE SDK 1.4.2	**CLDC 1.0**	**CLDC 1.1**
`AbstractCollection`	–	–
`AbstractList`	–	–
`AbstractMap`	–	–
`AbstractSequentialList`	–	–
`AbstractSet`	–	–
`ArrayList`	–	–
`Arrays`	–	–
`BitSet`	–	–
`Calendar`	–	–
`Collections`	–	–

Table 4-4. *The java.util Package (Continued)*

J2SE SDK 1.4.2	CLDC 1.0	CLDC 1.1
Currency	–	–
Date	Different	Same as CLDC 1.0
Dictionary	–	–
EventListenerProxy	–	–
EventObject	–	–
GregorianCalendar	–	–
HashMap	–	–
HashSet	–	–
Hashtable	Different	Same as CLDC 1.0
IdentityHashMap	–	–
LinkedHashMap	–	–
LinkedHashSet	–	–
LinkedList	–	–
ListResourceBundle	–	–
Locale	–	–
Observable	–	–
Properties	–	–
PropertyPermission	–	–
PropertyResourceBundle	–	–
Random	Different	Different
ResourceBundle	–	–
SimpleTimeZone	–	–
Stack	Same	Same
StringTokenizer	–	–
Timer	Same (MIDP)	Same (MIDP)
TimerTask	Same (MIDP)	Same (MIDP)
TimeZone	Different	Same as CLDC 1.0
TreeMap	–	–
TreeSet	–	–
Vector	Different	Same as CLDC 1.0
WeakHashMap	–	-

Collections

Although the full J2SE Collections API is not supported by CLDC, the old familiar `Vector` and `Hashtable` classes remain, as well as the lesser-known `Stack`. If you are familiar with the J2SE SDK `Vector` and `Hashtable` classes, you should have no trouble with them in MIDP.

Timers

MIDP includes the `Timer` and `TimerTask` classes that were introduced into J2SE in the 1.3 version of the SDK. These are the only J2SE classes that are not included in the CLDC but are included in MIDP.

`Timer`'s API is identical to the J2SE version with one exception. The constructor that specifies whether the thread is a daemon is missing, as daemon threads are not supported in MIDP. The `TimerTask` API is exactly the same in the J2SE SDK and MIDP.

Telling Time

J2SE has an impressive array of classes that can be used for specifying dates and times and translating to and from human-readable representations of dates and times. The J2SE time classes have four distinct responsibilities:

- *Points in time* are represented by instances of `java.util.Date`. If you think of time as a line graph, then an instance of `Date` is just a point on the line.
- *Calendars* are used for representing points in time with calendar fields like year, month, and day. If you're using a Gregorian calendar, for example, then you can translate from a single point in time to a set of calendar values like month, day, and hours, minutes, and seconds. In J2SE, `java.util.Calendar` is a parent class for calendars, while the `java.util.GregorianCalendar` class represents the Gregorian calendar system that is familiar to most of the world.
- *Formatting* classes translate between points in time and human-readable strings. In J2SE, `java.text.DateFormat` is the parent for classes that can both generate and parse human-readable strings representing points in time. Formatting classes are very likely to make use of a calendar. For example, a typical `DateFormat` implementation might use a `GregorianCalendar` to translate a point in time to a set of calendar values, which it would then format in a string.
- *Time zone* classes represent the time zones of the world. The `calendar` and `format` classes use a time zone to create a localized representation of a particular point in time. In J2SE, `java.util.TimeZone` is the parent class of all time zones, with `java.util.SimpleTimeZone` as a concrete implementation.

Understanding these classes and their interactions is a little tricky, and it's complicated by the fact that the APIs changed considerably between JDK 1.0 and JDK 1.1. The `java.util.Date` class used to have extra functionality in it; although the methods are deprecated, they're still present and may be confusing. Fortunately, you don't have to deal with this in the CLDC/MIDP world.

The situation is somewhat simpler in CLDC/MIDP. There are fewer classes, for one thing, and the `Date` class API has been cleaned up. In MIDP, the four responsibilities we just discussed are assigned to classes as follows:

- *Points in time* are represented by instances of `java.util.Date`, just like before. The `Date` class, in essence, is just a wrapper for a `long` value that indicates the number of milliseconds since midnight on January 1, 1970. (This is a standard way of representing time. It will work for about another 290 million years, so don't worry about another millennium bug.)
- *Calendars* are still represented by instances of `java.util.Calendar`. However, the `GregorianCalendar` class is no longer part of the public API. To get a `Calendar` instance, you can use the `getInstance()` factory method. Chances are you won't need to do this.
- *Formatting* classes are hidden from view in MIDP. One of the user interface classes, `javax.microedition.lcdui.DateField`, can convert a `Date` to a human-readable display, eliminating the need for you to mess around with date formatters yourself. Essentially `DateField` is a graphic wrapper around a `Date` instance. It also allows the user to edit calendar and clock fields to produce a new `Date` value. See Chapter 6 for a full discussion of `DateField`.
- *Time zones* are still represented by instances of `java.util.TimeZone`. `TimeZone` offers several static methods for examining the available time zones and getting an instance representing a particular time zone.

Summary

Developers are bombarded with information, and the best developers are the ones who can learn new material fast. Every once in a while, though, something you already know can be used again. This is one of those cases—something you already know about, the J2SE APIs, comes in very handy as you learn MIDP programming. MIDP's `java.lang`, `java.io`, and `java.util` packages contain classes that look and act a lot like the corresponding classes in J2SE.

CHAPTER 5

Creating a User Interface

Many MIDP applications are built to run on many different devices without modification. This is particularly difficult in the area of the user interface because devices have screens of all sizes, in grayscale and in color. Furthermore, devices vary widely in their input capabilities, from numeric keypads to alphabetic keyboards, soft keys, and even touch screens. The minimum screen size mandated by MIDP is 96×54 pixels, with at least one bit of color depth.[1] As for input, MIDP is fairly open ended: devices are expected to have some type of keyboard, or a touch screen, or possibly both.

Given the wide variety of devices that are compliant with MIDP, there are two ways to create applications that work well on all devices:

- *Abstraction*: Specify a user interface in abstract terms, relying on the MIDP implementation to create something concrete. Instead of saying something like, "Display the word 'Next' on the screen above the soft button," you say, "Give me a `Next` command somewhere in this interface."
- *Discovery*: The application learns about the device at runtime and tailors the user interface programmatically. You might, for example, find out how big the device's screen was in order to scale your user interface appropriately.

The MIDP APIs support both methods. Abstraction is the preferred method because it involves less code in your application and more work by the MIDP implementation. In some cases, like games, you need to be more specific about the user interface; these types of applications will discover the capabilities of a device and attempt to tailor their behavior appropriately. MIDP's user interface APIs are designed so that it's easy to mix the two techniques in the same application.

The View from the Top

MIDP contains user interface classes in the `javax.microedition.lcdui` and `javax.microedition.lcdui.game` packages. The device's display, as seen by the MIDlet, is represented by an instance of the `Display` class, accessed from a factory method, `getDisplay()`. `Display`'s main purpose in life is to keep track of what is currently shown, which is an instance

1. Color depth is the number of bits that determine the color of a pixel on the screen. One bit allows for two colors (usually black and white). Four bits allows for 16 colors, which could be different levels of gray or a palette of other colors. In general, N bits allow 2 to the power of N colors or levels of gray.

of Displayable. If you think of Display as an easel, a Displayable instance is akin to a canvas on that easel.

MIDlets can change the contents of the display by passing Displayable instances to Display's setCurrent() method. This is the basic function of a typical MIDlet:

1. Show a Displayable.
2. Wait for input.
3. Decide what Displayable should be next.
4. Repeat.

Displayable has a small family of subclasses that represent various types of user interfaces. Figure 5-1 shows the lineage.

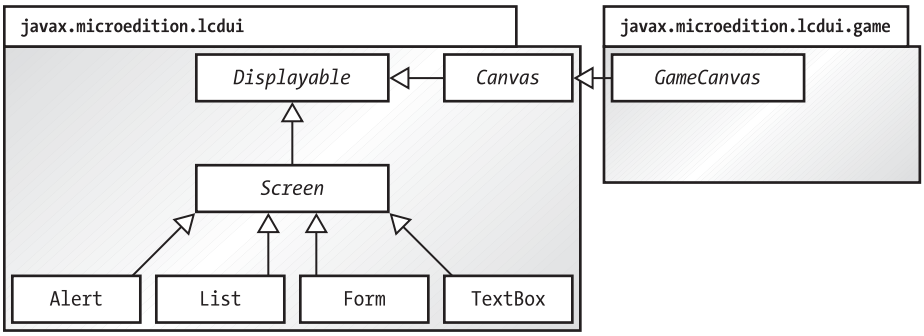


Figure 5-1. *Displayables in the javax.microedition.lcdui and javax.microedition.lcdui.game package*

Displayable's progeny are split between two branches that correspond to the two methods for creating generalized user interfaces, abstraction and discovery. The Screen class represents displays that are specified in abstract terms.

These screens contain standard user interface items like combo boxes, lists, menus, and buttons. Four subclasses provide a wide range of functionality, as illustrated in Figure 5-2.

The remainder of this chapter is devoted to explaining the simplest of these four classes: TextBox and Alert. The next chapter explores the more flexible List and Form.

For particularly demanding or idiosyncratic displays, you'll have to create a subclass of Canvas. Your MIDlet will assume responsibility for most of the drawing, but you get much finer control over what is shown and how user input is handled. Canvas supplies methods that allow your MIDlet to learn about its environment—the size of the display, for example, and which kinds of events are supported by the device. User interfaces built on Canvas discover the attributes of a device and attempt to create something that looks reasonable. Chapter 13 explains Canvas-based user interfaces in detail. GameCanvas provides user interface functionality specifically for game displays. This API is explained in Chapter 14.

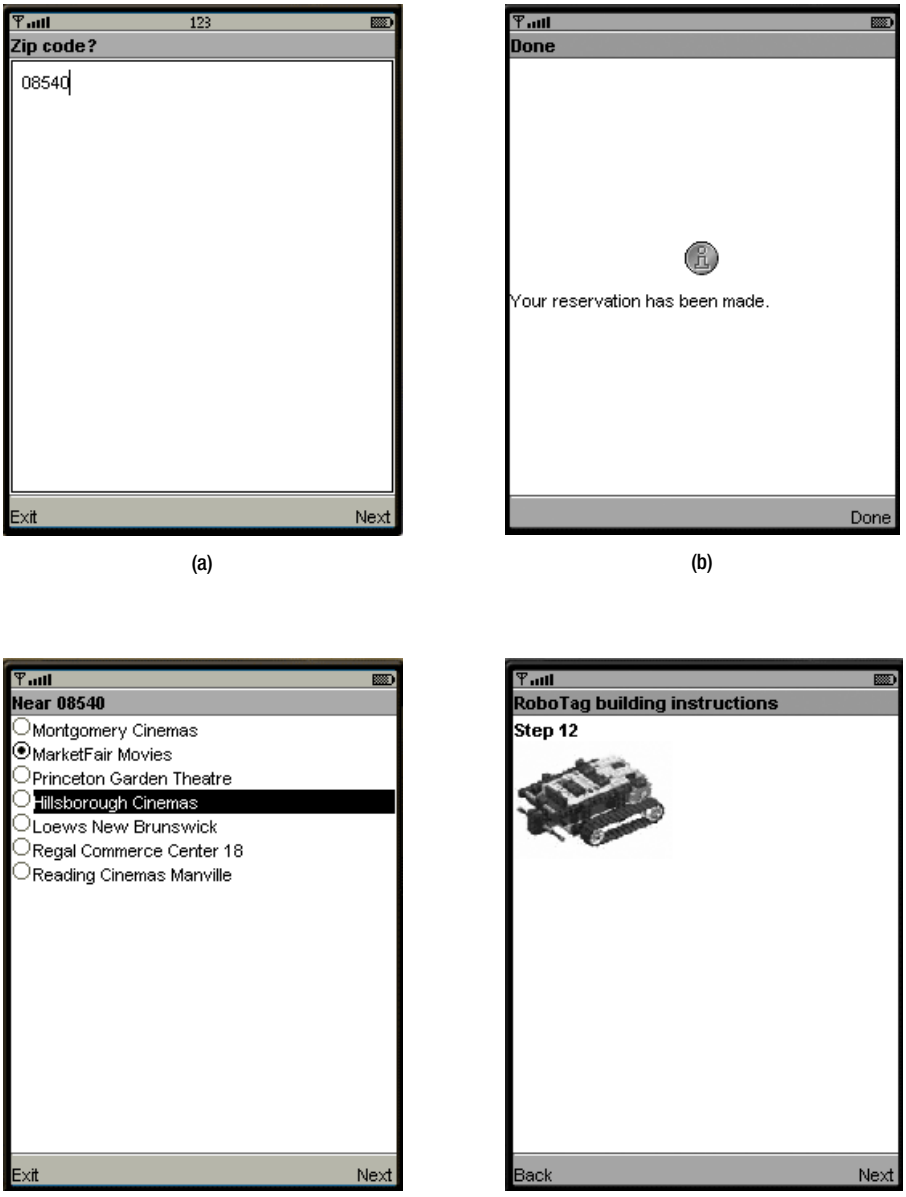


Figure 5-2. *The four children of Screen: (a) TextBox, (b) Alert, (c) List, and (d) Form*

Using Display

`Display` manages a device's screen. You can get a reference to the device's display by supplying a MIDlet reference to the static `getDisplay()` method. Typically, you'll do this in the `startApp()` method of a MIDlet:

```
public void startApp() {
  Display d = Display.getDisplay(this);
  // ...
}
```

You may be tempted to call `getDisplay()` in a MIDlet's constructor, but according to the specification, `getDisplay()` can only be called after the beginning of the MIDlet's `startApp()` method. If you try to call it before `startApp()` is called, your MIDlet may throw an exception and terminate before starting!

Once you've got a reference to a device's `Display`, you'll just need to create something to show (an instance of `Displayable`) and pass it to one of `Display`'s `setCurrent()` methods:

```
public void setCurrent(Displayable next)
public void setCurrent(Alert alert, Displayable nextDisplayable)
```

The second version is used when you want to show a temporary message (an `Alert`) followed by something else. We'll talk more about `Alert`s at the end of this chapter.

`Display`'s `getCurrent()` method returns a reference to what's currently being shown. Note that a MIDlet may return a valid object from `getCurrent()` even if it is not visible to the user. This could happen on a device running multiple MIDlets simultaneously, for example. Note that the `Displayable` interface has a method called `isShown()` that indicates whether the given object is actually being shown on the device screen.

You can also query a `Display` to determine its capabilities, which is helpful for applications that need to adapt themselves to different types of displays. The `numColors()` method returns the number of distinct colors supported by this device, while the `isColor()` method tells whether the device supports color or grayscale. A `Display` for a device supporting 16 levels of gray, for example, would return `false` from `isColor()` and `16` from `numColors()`. You can also find out whether the device supports transparency by calling `numAlphaLevels()`, which returns the number of transparency levels. The minimum return value is 2, indicating that image pixels with full transparency and full opacity are supported. Return values greater than 2 indicate that alpha blending is supported. The `getColor()` and `getBorderStyle()` methods are used for finding out colors and line styles from the system user interface scheme. These are useful for drawing custom items, a topic that is covered in Chapter 7. The `flashBacklight()` and `vibrate()` methods invoke the corresponding features of the device. These are more fully discussed in Chapter 14.

Event Handling with Commands

`Displayable`, the parent of all screen displays, supports a very flexible user interface concept, the command. A *command* is something the user can invoke—you can think of it as a GUI button. Like a button, it has a title, like OK or Cancel, and your application can respond appropriately when the user invokes the command. The premise is that you want a command to be available to the user, but you don't really care how it is shown on the screen or exactly how the user invokes it—keypad button, soft button, touch screen, voice recognition, whatever.

Every `Displayable` keeps a list of its `Command`s. You can add and remove `Command`s using the following methods:

```
public void addCommand(Command cmd)
public void removeCommand(Command cmd)
```

Creating Commands

In MIDP, commands are represented by instances of the `Command` class. To create a `Command`, just supply a name, a type, and a priority. The name is usually shown on the screen. The type can be used to signify a commonly used command. It must be one of the values defined in the `Command` class. Table 5-1 shows the type values and their meanings.

Table 5-1. *Command Types*

Name	Meaning
`OK`	Confirms a selection
`CANCEL`	Cancels pending changes
`BACK`	Moves the user back to a previous screen
`STOP`	Stops a running operation
`HELP`	Shows application instructions
`SCREEN`	Indicates generic type for specific application commands

To create a standard `OK` command, for example, you would do this:

```
Command c = new Command("OK", Command.OK, 0);
```

To create a command specific to your application, you might do this:

```
Command c = new Command("Launch", Command.SCREEN, 0);
```

It's up to the MIDP implementation to figure out how to show the commands. In the Sun J2ME Wireless Toolkit emulator, commands are assigned to the two soft buttons. A *soft button* is a button on the device keypad with no predefined function. A soft button can serve a different purpose at different times. If there are more commands than there are soft buttons, the commands that don't fit will be grouped into a menu that is assigned to one of the soft buttons.

A simple priority scheme determines who wins when there are more commands than available screen space. Every command has a priority that indicates how hard the display system should try to show the command. Lower numbers indicate a higher priority. If you add a command with priority 0, then several more with priority 1, the priority 0 command will show up on the screen directly. The other commands will most likely end up in a secondary menu.

Long labels are supported on commands. The actual MIDP implementation decides which label it will use based on the available screen space and the size of the labels. You can create a command with a short and long label like this:

```
Command c = new Command("Run", "Run simulation", Command.SCREEN, 0);
```

The `Command` class provides `getLabel()`, `getLongLabel()`, and `getCommandType()` methods for retrieving information about commands.

Responding to Commands

By themselves, Commands aren't very exciting. They'll show up on the screen, but nothing happens automatically when a user invokes a command. An object called a *listener* is notified when the user invokes any command in a Displayable. This follows the basic form of the JavaBeans event model; a Displayable is a *unicast event source*. A Displayable fires off an event every time the user invokes one of its Commands.

The listener is an object that implements the CommandListener interface. To register the listener with a Displayable, use the following method:

```
public void setListener(CommandListener l)
```

Displayable is a unicast event source because it can only have one listener object. (Multicast event sources can have multiple listeners and use an add... method for adding listeners rather than a set... method.)

Implementing a CommandListener is a matter of defining a single method:

```
public void commandAction(Command c, Displayable s)
```

When a command is invoked, the Displayable that contains it calls the commandAction() method of the registered listener.

■ **Tip** Event listeners should not perform lengthy processing inside the event-handling thread. The system uses its own thread to call commandAction() in response to user input. If your implementation of commandAction() does any heavy thinking, it will tie up the system's event-handling thread. If you have anything complicated to do, use your own thread. Some JVM implementations may protect itself from what is effectively a denial-of-service attack and terminate threads or applications that abuse system thread.

A Simple Example

By way of illustration, consider the following class:

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class Commander extends MIDlet {
  public void startApp() {
    Displayable d = new TextBox("TextBox", "Commander", 20, TextField.ANY);
    Command c = new Command("Exit", Command.EXIT, 0);
    d.addCommand(c);
    d.setCommandListener(new CommandListener() {
      public void commandAction(Command c, Displayable s) {
        notifyDestroyed();
      }
    } );
```

```
    Display.getDisplay(this).setCurrent(d);
  }

  public void pauseApp() { }

  public void destroyApp(boolean unconditional) { }
}
```

This MIDlet creates a `TextBox`, which is a kind of `Displayable`, and adds a single command to it. The listener is created as an anonymous inner subclass. In Sun's toolkit, this MIDlet appears as shown in Figure 5-3.

Figure 5-3. *A simple MIDlet with a single command, Exit*

Figure 5-3 shows the `Exit` command being mapped to one of the MIDP simulator's soft buttons. If you add another command to this MIDlet, it will be mapped to the other soft button. If you continue adding commands, the ones that don't fit on the screen will be put into an off-screen menu. For example, a screen with four commands shows up in the MIDP simulator as illustrated in Figure 5-4a.

If you press the soft button for `Menu`, you'll see the remainder of the commands as shown in Figure 5-4b. Menu items can now be selected by pressing a number or using the arrow keys for navigation. In the example shown in Figure 5-4, the `Exit` command is given a higher priority (lower number) than the other commands, which ensures that it appears directly on the screen. The other commands, with a lower priority, are relegated to the command menu.

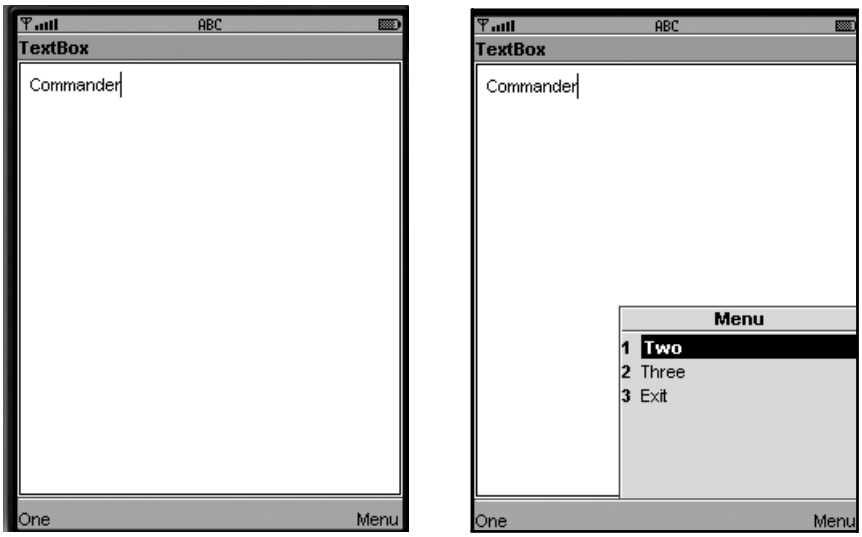


Figure 5-4. *This MIDlet has more commands than the device has soft buttons. Invoking the (a) system-generated Menu command brings up the (b) remaining commands.*

All `Displayables` have a title and an optional ticker. The `title` is just what you expect: a string that appears at the top of a `Displayable`. As you saw in Figure 5-3, the title of the screen is TextBox. Subclasses of `Screen` have constructors that set the title, but the title may also be accessed using the following methods:

```
public void setTitle(String newTitle)
public String getTitle()
```

Tickers

A ticker is simply a bit of text that scrolls across the top of a `Displayable`; it is named after old-fashioned stock tickers.

The `Ticker` class is a simple wrapper for a string. To add a ticker to a screen, you would do something like this:

```
// Displayable d = ...
Ticker ticker = new Ticker("This is the ticker message!");
d.setTicker(ticker);
```

Figure 5-5 shows a ticker in action.

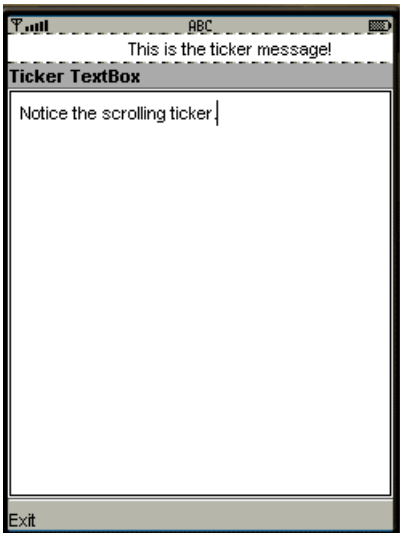


Figure 5-5. *A ticker scrolls across the top of a screen.*

Screens

The remainder of this chapter and all of Chapter 6 are devoted to `Screen` and its subclasses, which is the left branch of the hierarchy shown in Figure 5-1. `Screen` is the base class for all classes that represent generalized user interfaces. This class has no methods of its own, but inherits all from `Displayable`.

`Canvas`, by contrast, is a base class for specialized interfaces, such as those for games. `Canvas` will be fully covered later, in Chapter 13.

In the coming sections, we'll explore each of `Screen`'s child classes.

TextBox, the Simplest Screen

The simplest type of screen is the `TextBox`, which you've already seen in action. `TextBox` allows the user to enter a string. Keep in mind that on a garden-variety MIDP device, text input is a tedious process. Many devices only have a numeric keypad, so entering a single character is a matter of one, two, three, or even more button presses. A good MIDlet requires minimal user input.

That said, your MIDlet may need some kind of input—perhaps a zip code, or a short name, or some kind of password. In these cases, you'll probably want to use a `TextBox`.

A `TextBox` is created by specifying four parameters:

```
public TextBox(String title, String text, int maxSize, int constraints)
```

The title is used as the screen title, while `text` and `maxSize` determine the initial text and maximum size of the text box. Finally, `constraints` can be used to restrict the user's input. Constants from the `TextField` class are used to specify the type of input required:

- `ANY` allows any type of input that is supported by the device.
- `NUMERIC` restricts the input to integers.
- `DECIMAL` allows numbers with fractional parts.
- `PHONENUMBER` requires a telephone number.
- `EMAILADDR` input must be an e-mail address.
- `URL` input must be a web address.

It's up to the implementation to determine how these constraints are enforced. The toolkit emulators simply don't allow invalid input; for example, a `NUMERIC` `TextBox` doesn't allow you to enter alphabetic characters.

The preceding constraints may be combined with the flags listed next. Constraints limit the behavior of users, while flags define the behavior of the `TextBox`.

- `PASSWORD` characters are not shown when entered; generally, they are represented by asterisks.
- `UNEDITABLE` indicates text that cannot be edited.
- `SENSITIVE` is used to flag text that the implementation should not store. Some input schemes store input from the user for later use in autocompletion. This flag indicates that the text is off limits and should not be saved or cached.
- `NON_PREDICTIVE` indicates that you are expecting the user to enter text that any text-predicting input scheme will probably not be able to guess. For example, if you're expecting the user to enter an order number like Z51002S, you would use this flag to tell the input scheme to not bother trying to predict the input.
- `INITIAL_CAPS_WORD` is used for input where each word should be capitalized.
- `INITIAL_CAPS_SENTENCE` indicates input where the first character of each sentence should be capitalized.

If you don't want the `TextBox` to perform any validation, use `ANY` or its numerical equivalent, `0`, for the `constraints` parameter in the constructor.

The flags may be combined with any of the other constraints using the `OR` operator. For example, to create a `TextBox` that constrains input to an e-mail address but keeps the entered data hidden, you would do something like this:

```
Displayable d = new TextBox("Email", "", 64,
        TextField.EMAILADDR | TextField.PASSWORD);
```

If you think about it, though, `PASSWORD` is probably more trouble than it's worth. The point of `PASSWORD` fields, at least on desktop machines, is to keep someone walking past your computer

screen from seeing your secret password. For every character you enter, the password field shows an asterisk or some other symbol. As you type your secret password, all that shows up on the screen is a line of asterisks. On mobile phones and other small devices, this is less of a concern because the screens are smaller and much more difficult to read than a typical desktop monitor.

Furthermore, the difficulty of entering data on a small device means that it will be hard to correctly enter passwords if you are typing blind. Mobile phones, for example, typically require you to press keys several times to enter a single letter. On Sun's toolkit emulator, pressing the 7 key twice enters the letter "Q." On a real device, you would have to enter a password "gandalf" with the following sequence of key presses: 4, 2, 6, 6, 3, 2, 5, 5, 5, 3, 3, 3. Without visual feedback, it would be extremely easy to make a mistake when entering a password. ("Did I press the 5 key two times or three times?") The J2ME Wireless Toolkit emulator shows the current character, but previously typed characters are shown as asterisks. Good passwords typically have mixed case, numbers, and possibly punctuation; these would be hard to enter correctly.

Password fields (whether or not they use the `PASSWORD` flag) should be protected with the `SENSITIVE` flag so that the password doesn't show up in any system dictionaries or pop up unexpectedly when the user is entering other text.

A method in the `TextBox` class called `setInitialInputMode(String characterSubset)` is used to suggest to the implementation what input mode would be best suited to the expected text. You can only suggest the input mode, and you have no way of knowing whether the implementation has honored the request. The string passed to the method can be one of the constants from the `J2SE java.lang.Character.UnicodeBlock` class, prepended with "UCB_". For example, you might pass "UCB_BASIC_LATIN" or "UCB_KATAKANA" to this method. You can also use input subsets defined by `java.awt.im.InputSubset` by prepending them with "IS_". For example, "IS_LATIN" or "IS_KANJI" would be valid. Finally, the character subsets "MIDP_UPPERCASE_LATIN" and "MIDP_LOWERCASE_LATIN" are also defined.

The input mode is complementary to the text constraints and flags. You might specify `ANY` for the constraints, then call `setInitialInputMode("MIDP_LOWERCASE_LATIN")` to request that the implementation begin by allowing lowercase input. This doesn't prevent the user from changing the input mode, it just starts things off on the right foot.

Using Alerts

An `alert` is an informative message shown to the user. In the MIDP universe, there are two flavors of alert:

- A `timed` alert is shown for a certain amount of time, typically just a few seconds. It displays an informative message that does not need to be acknowledged, like "Your transaction is complete," or "I can't do that right now, Dave."
- A `modal` alert stays up until the user dismisses it. Modal alerts are useful when you need to offer the user a choice of actions. You might display a message like "Are you ready to book these tickets?" and offer `Yes` and `No` commands as options.

MIDP alerts can have an associated icon, like a stop sign or question mark. Alerts may even have an associated sound, although this depends on the implementation. MIDP alerts are very much the same concept as modal dialog boxes in windowing systems like MacOS and Windows. Figure 5-6 shows a typical `Alert`.

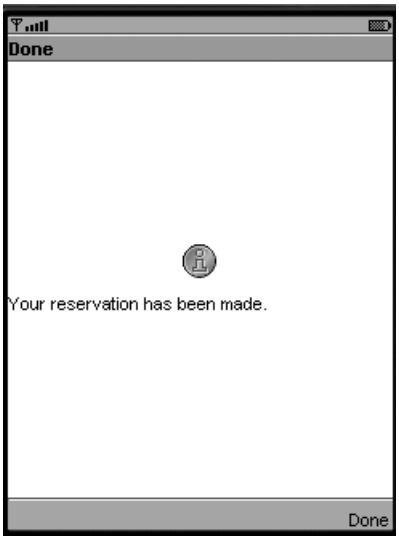


Figure 5-6. *Alerts are similar to modal dialog boxes in a desktop windowing system.*

Alerts are represented by instances of the `javax.microedition.lcdui.Alert` class, which offers the following constructors:

```
public Alert()
public Alert(String title, String alertText, Image alertImage, AlertType alertType)
```

Any or all of the parameters in the second constructor may be `null`. (Don't worry about the `Image` class right now; we'll discuss it in the next chapter in the section on `Lists`.)

By default, timed `Alerts` are created using a default timeout value; you can find out the default value by calling `getDefaultTimeout()`. To change the `Alert`'s timeout, call `setTimeout()` with the timeout value in milliseconds. A special value, `FOREVER`, may be used to indicate that the `Alert` is modal.

You could create a simple timed `Alert` with the following code:

```
Alert alert = new Alert("Sorry", "I'm sorry, Dave...", null, null);
```

To explicitly set the timeout value to five seconds, you could do this:

```
alert.setTimeout(5000);
```

If, instead, you wanted a modal alert, you would use the special value `FOREVER`:

```
alert.setTimeout(Alert.FOREVER);
```

The MIDP implementation will automatically supply a way to dismiss a modal alert. Sun's reference implementation, for example, provides a `Done` command mapped to a soft button. This command is exposed as the static member `DISMISS_COMMAND`, allowing you to register your own command listener and explicitly recognize this command. You can add your own commands to an `Alert` using the usual `addCommand()` method. The first time you call `addCommand()`, the system's `Done` command is removed.

The default behavior for Alerts automatically advances to the next screen when the Alert is dismissed or times out. You can specify the next screen by passing it and the Alert to the two-argument setCurrent() method in Display. If you call the regular one-argument setCurrent() method, the previous screen is restored when the Alert is dismissed. Alert types serve as hints to the underlying MIDP implementation. The implementation may use the alert type to decide what kind of sound to play when the alert is shown. The AlertType class provides five types, accessed as static member variables: ALARM, CONFIRMATION, ERROR, INFO, and WARNING.

There is an optional indicator to an Alert. By default, no indicator is present, but you can add one by passing a Gauge to Alert's setIndicator() method. (Gauge is presented in the next chapter in the section on Forms.) The indicator is handy for showing progress in a network connection or a long computation.

The following example, TwoAlerts, shows both types of alert. It features a main TextBox that is displayed when the MIDlet begins. Two commands, Go and About, provide access to the alerts. The Go command shows a timed alert that contains a message about a fictitious network error. The About command displays a modal alert that could contain copyright information. A third command, Exit, provides a way to exit the MIDlet. Keep in mind that all three commands may not fit on the screen; some of them may be accessible from a secondary menu.

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class TwoAlerts
    extends MIDlet
    implements CommandListener {
  private Display mDisplay;

  private TextBox mTextBox;
  private Alert mTimedAlert;
  private Alert mModalAlert;

  private Command mAboutCommand, mGoCommand, mExitCommand;

  public TwoAlerts() {
    mAboutCommand = new Command("About", Command.SCREEN, 1);
    mGoCommand = new Command("Go", Command.SCREEN, 1);
    mExitCommand = new Command("Exit", Command.EXIT, 2);

    mTextBox = new TextBox("TwoAlerts", "", 32, TextField.ANY);
    mTextBox.addCommand(mAboutCommand);
    mTextBox.addCommand(mGoCommand);
    mTextBox.addCommand(mExitCommand);
    mTextBox.setCommandListener(this);

    mTimedAlert = new Alert("Network error",
        "A network error occurred. Please try again.",
        null,
        AlertType.INFO);
```

```
    mModalAlert = new Alert("About TwoAlerts",
         "TwoAlerts is a simple MIDlet that demonstrates the use of Alerts.",
         null,
         AlertType.INFO);
     mModalAlert.setTimeout(Alert.FOREVER);
   }

   public void startApp() {
     mDisplay = Display.getDisplay(this);

     mDisplay.setCurrent(mTextBox);
   }

   public void pauseApp() {
   }

   public void destroyApp(boolean unconditional) {}

   public void commandAction(Command c, Displayable s) {
     if (c == mAboutCommand)
       mDisplay.setCurrent(mModalAlert);
     else if (c == mGoCommand)
       mDisplay.setCurrent(mTimedAlert, mTextBox);
     else if (c == mExitCommand)
       notifyDestroyed();
   }
}
```

Summary

MIDP's main user interface classes are based on abstractions that can be adapted to devices that have different display and input capabilities. Several varieties of prepackaged screen classes make it easy to create a user interface. Screens have a title and an optional ticker. Most importantly, screens can contain `Commands`, which the implementation makes available to the user. Your application can respond to commands by acting as a listener object. This chapter described `TextBox`, a screen for accepting user input, and `Alert`, a simple screen for displaying information. In the next chapter, we'll get into the more complex `List` and `Form` classes.

CHAPTER 6

Lists and Forms

In the last chapter, you learned about MIDP's simpler screen classes. Now we're getting into deeper waters, with screens that show lists and screens with mixed types of controls.

Using Lists

After `TextBox` and `Alert`, the next simplest `Screen` is `List`, which allows the user to select items (called *elements*) from a list of choices. A text string or an image is used to represent each element in the list. `List` supports the selection of a single element or of multiple elements.

There are two main types of `List`, denoted by constants in the `Choice` interface:

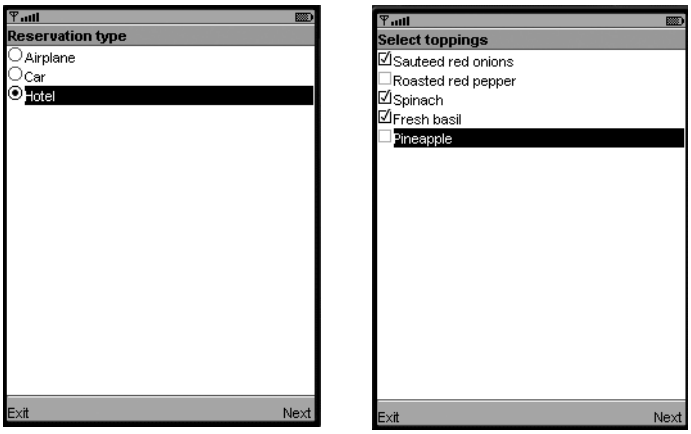
- `MULTIPLE` designates a list where multiple elements may be selected simultaneously.
- `EXCLUSIVE` specifies a list where only one element may be selected. It is akin to a group of radio buttons.

Understanding List Types

For both `MULTIPLE` and `EXCLUSIVE` lists, selection and confirmation are separate steps. In fact, `List` does not handle confirmation for these types of lists—your MIDlet will need to provide some other mechanism (probably a `Command`) that allows users to confirm their choices. `MULTIPLE` lists allow users to select and deselect various elements before confirming the selection. `EXCLUSIVE` lists also permit users to change their minds several times before confirming the selection.

Figure 6-1a shows one implementation of an `EXCLUSIVE` list. With this list, the user navigates through the list using the arrow up and down keys. An element can selected by pressing the select button on the device. Figure 6-1b shows a `MULTIPLE` list. It works basically the same way as an `EXCLUSIVE` list, but multiple elements can be selected simultaneously. As before, the user moves through the list with the up and down arrow buttons. The select button toggles the selection of a particular element.

A further refinement of `EXCLUSIVE` also exists: `IMPLICIT` lists combine the steps of selection and confirmation. The `IMPLICIT` list acts just like a menu. Figure 6-2 shows an `IMPLICIT` list with images and text for each element. When the user hits the select button, the list immediately fires off an event, just like a `Command`. An `IMPLICIT` list is just like an `EXCLUSIVE` list in that the user can only select one of the list elements. But with `IMPLICIT` lists, there's no opportunity for the user to change his or her mind before confirming the selection.



(a) (b)

Figure 6-1. *List types: (a) EXCLUSIVE and (b) MULTIPLE*

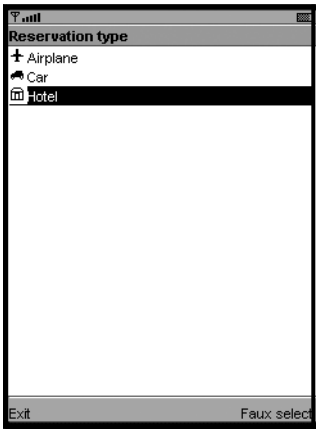


Figure 6-2. *IMPLICIT lists combine selection and confirmation.*

Event Handling for IMPLICIT Lists

When the user makes a selection in an `IMPLICIT` `list`, the `commandAction()` method of the `list`'s `CommandListener` is invoked. A special value is passed to `commandAction()` as the `Command` parameter:

```
public static final Command SELECT_COMMAND
```

For example, you can test the source of command events like this:

```
public void commandAction(Command c, Displayable s) {
  if (c == nextCommand)
    // ...
  else if (c == List.SELECT_COMMAND)
    // ...
}
```

The example at the end of this section, in Listing 6-1, demonstrates an `IMPLICIT` `list`.

You can also use the `setSelectCommand()` method to specify your own `Command` to be used for selections instead of having to use the `SELECT_COMMAND`.

Creating Lists

To create a `List`, specify a title and a list type. If you have the element names and images available ahead of time, you can pass them in the constructor:

```
public List(String title, int type)
public List(String title, int type,
    String[] stringElements, Image[] imageElements)
```

The `stringElements` parameter cannot be `null` but can be empty; however, `imageElements` may contain `null` array elements. If the image associated with a list element is null, the element is displayed using just the string. If both the string and the image are defined, the element will display using the image and the string.

Some `Lists` will have more elements than can be displayed on the screen. Indeed, the actual number of elements that will fit varies from device to device. But don't worry: `List` implementations automatically handle scrolling up and down to show the full contents of the `List`. MIDlet developers have no control over how the implementation handles this scrolling.

About Images

Our romp through the `List` class yields a first look at images. Instances of the `javax.microedition.lcdui.Image` class represent images in MIDP. The specification dictates implementations be able to load images files in PNG format.[1] This format supports both a transparent color and lossless compression.

`Image` has no constructors, but the `Image` class offers a handful of `createImage()` factory methods for obtaining `Image` instances. The first are for loading images from PNG data.

```
public static Image createImage(String name)
public static Image createImage(byte[] imagedata, int imageoffset,
    int imagelength)
public static Image createImage(InputStream stream)
```

The first method attempts to create an `Image` from the named file, which should be packaged inside the JAR that contains your MIDlet. You must use an absolute pathname or the image file will not be found. The second method creates an `Image` using data in the supplied array. The data starts at the given array offset, `imageoffset`, and is `imagelength` bytes long. The third method creates an `Image` from an `InputStream`.

Images may be *mutable* or *immutable*. Mutable `Images` can be modified by calling `getGraphics()` and using the returned `Graphics` object to draw on the image. (For full details on `Graphics`, see Chapter 13.) If you try to call `getGraphics()` on an immutable `Image`, an `IllegalStateException` will be thrown.

1. MIDP implementations are not required to recognize all varieties of PNG files. The documentation for the `Image` class has the specifics.

The createImage() methods described previously return immutable Images. To create a mutable Image, use the following method:

```
public static Image createImage(int width, int height)
```

Typically you would create a mutable Image for off-screen drawing, perhaps for an animation or to reduce flicker if the device's display is not double buffered.

Any Image you pass to Alert, ChoiceGroup, ImageItem, or List should be immutable. To create an immutable Image from a mutable one, use the following method:

```
public static Image createImage(Image image)
```

You can also create an Image from a portion of another Image using the following method:

```
public static Image createImage(Image image,
    int x, int y, int width, int height, int transform)
```

This method takes the part of the original image described by x, y, width, and height; applies the specified transformation; and returns the result as an immutable Image. The possible transformations are described by constants in the javax.microedition.lcdui.game.Sprite class and include things like mirroring and 90-degree rotation.

Image also includes methods that handle image data as an int array. We'll talk about these methods later in Chapter 13.

How do you figure out what size Images you need? Actually, Display provides methods that return information about the optimal width and height for various types of images:

```
public int getBestImageHeight(int imageType);
public int getBestImageWidth(int imageType);
```

The imageType parameter should be one of Display's constants: LIST_ELEMENT, ALERT, or CHOICE_GROUP_ELEMENT. (You'll learn all about ChoiceGroup later in this chapter.) If you were building a List, you could query Display to find the best size for element images. Assuming you had packaged icons of various sizes in your application, you could select the best-sized images at runtime.

Editing a List

List provides methods for adding items, removing elements, and examining elements. Each element in the List has an index. The first element is at index 0, the next at index 1, and so forth. You can replace an element with set() or add an element to the end of the list with append(). The insert() method adds a new element to the list at the given index; this bumps all elements at that position and higher up by one.

```
public void set(int elementNum, String stringPart, Image imagePart)
public void insert(int elementNum, String stringPart, Image imagePart)
public int append(String stringPart, Image imagePart)
```

You can examine the string or image for a given element by supplying its index. Similarly, you can use delete() to remove an element from the List.

```
public String getString(int elementNum)
public Image getImage(int elementNum)
public void delete(int elementNum)
public void deleteAll()
```

The `deleteAll()` method removes every element from the `List`.

Finally, the `size()` method returns the number of elements in the `List`.

Although you usually give the MIDP implementation the responsibility of displaying your `List`, methods in `List` give you some control over the appearance of a `List`. The first method, `setFitPolicy()`, tells the `List` how it should handle elements whose text is wider than the screen. The possible values (from the `Choice` interface) are the following:

- `TEXT_WRAP_ON` denotes that long elements will be wrapped to multiple lines.
- `TEXT_WRAP_OFF` denotes that long elements will be truncated at the edge of the screen.
- `TEXT_WRAP_DEFAULT` indicates that the implementation should use its default fit policy.

Another new method is `setFont()`, which allows you to specify the font that will be used for a specific `List` element. (Fonts will be fully discussed in Chapter 13.) The current `Font` for an element can be retrieved by calling `getFont()`. Calls to `setFitPolicy()` and `setFont()` only serve as hints; it's up to the implementation to decide how to display the `List` and whether the requested fit policy or font can be honored.

Working with List Selections

You can find out whether a particular element in a `List` is selected by supplying the element's index to the following method:

```
public boolean isSelected(int index)
```

For `EXCLUSIVE` and `IMPLICIT` lists, the index of the single selected element is returned from the following method:

```
public int getSelectedIndex()
```

If you call `getSelectedIndex()` on a `MULTIPLE` list, it will return `-1`.

To change the current selection programmatically, use `setSelectedIndex()`.

```
public void setSelectedIndex(int index, boolean selected)
```

Finally, `List` allows you to set or get the selection state en masse with the following methods. The supplied arrays must have as many array elements as there are list elements.

```
public int getSelectedFlags(boolean[] selectedArray_return)
public void setSelectedFlags(boolean[] selectedArray)
```

An Example

The example in Listing 6-1 shows a simple MIDlet that could be part of a travel reservation application. The user chooses what type of reservation to make. This example uses an `IMPLICIT` list, which is essentially a menu.

Listing 6-1. *The TravelList Source Code*

```
import java.io.*;
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class TravelList
    extends MIDlet
    implements CommandListener {
  private List mList;
  private Command mExitCommand, mNextCommand;

  public TravelList() {
    String[] stringElements = { "Airplane", "Car", "Hotel" };
    Image[] imageElements = { loadImage("/airplane.png"),
        loadImage("/car.png"), loadImage("/hotel.png") };
    mList = new List("Reservation type", List.IMPLICIT,
        stringElements, imageElements);
    mNextCommand = new Command("Next", Command.SCREEN, 0);
    mExitCommand = new Command("Exit", Command.EXIT, 0);
    mList.addCommand(mNextCommand);
    mList.addCommand(mExitCommand);
    mList.setCommandListener(this);
  }

  public void startApp() {
    Display.getDisplay(this).setCurrent(mList);
  }

  public void commandAction(Command c, Displayable s) {
    if (c == mNextCommand || c == List.SELECT_COMMAND) {
      int index = mList.getSelectedIndex();
      Alert alert = new Alert("Your selection",
          "You chose " + mList.getString(index) + ".",
          null, AlertType.INFO);
      Display.getDisplay(this).setCurrent(alert, mList);
    }
    else if (c == mExitCommand)
      notifyDestroyed();
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}
```

```
  private Image loadImage(String name) {
    Image image = null;
    try {
      image = Image.createImage(name);
    }
    catch (IOException ioe) {
      System.out.println(ioe);
    }

    return image;
  }
}
```

To see images in this example, you'll need to either download the examples from the book's web site or supply your own images. With the J2ME Wireless Toolkit, image files should go in the `res` directory of your toolkit project directory. `TravelList` expects to find three images named `airplane.png`, `car.png`, and `hotel.png`.

Construction of the `List` itself is very straightforward. This application also includes a `Next` command and an `Exit` command, which are both added to the `List`. The `TravelList` instance is registered as the `CommandListener` for the `List`. If the `Next` command or the `List`'s `IMPLICIT` command is fired off, you simply retrieve the selected item from the `List` and show it in an `Alert`.

The `Next` command, in fact, is not strictly necessary in this example since you can achieve the same result by clicking the select button on one of the elements in the `List`. Nevertheless, it might be a good idea to leave it there. Maybe all of the other screens in your application have a `Next` command, so you could keep it for user interface consistency. It never hurts to provide the user with more than one consistent way of doing things.

The difference between `EXCLUSIVE` and `IMPLICIT` lists can be subtle. Try changing the `List` in this example to `EXCLUSIVE` to see how the user experience is different.

Creating Advanced Interfaces with Forms

A `Form` is a screen that can include an arbitrary collection of user-interface controls, called *items*. In a movie ticket reservation MIDlet, you might use a form to allow the user to enter a date and a Zip code on one screen.

Keep in mind that the minimum screen size for a MID is 96×54 pixels. You can't fit a whole lot on a screen this size, nor should you try to. Forms that don't fit on the screen will automatically be made scrollable if needed, so your MIDlet will be able to show forms, regardless of the screen size. Scrolling forms tend to be confusing to users, however, so you should keep your forms as small as possible.

The `javax.microedition.ldcui.Form` class itself is fairly simple. One way to create a `Form` is by specifying a title:

```
public Form(String title)
```

In essence, a `Form` is a collection of items. Each item is represented by an instance of the `Item` class. If you have all the items ahead of time, you can pass them to `Form`'s other constructor:

```
public Form(String title, Item[] items)
```

As a subclass of `Screen` and `Displayable`, `Form` inherits both a title and a ticker. Given the small screen size of a typical MIDP device, however, you may want to avoid using a ticker with your forms.

■ **Caution** The use of a ticker may also affect battery life on a small device, due to the need to constantly update the ticker's display area.

`Form`'s grandparent class, `Displayable`, gives `Form` the capabilities of displaying commands and firing command events. Again, you should probably keep commands simple with forms; in many cases a `Next` and a `Back` will probably be sufficient.

As with any `Displayable`, the basic strategy for showing a `Form` is to create one and pass it to `Display`'s `setCurrent()` method. If you have a form that is larger than the `Display`, you may want to use the `setCurrentItem()` method in `Display`. This method makes the form containing the item visible, then it scrolls the form so the item is visible and has input focus.

Managing Items

Items may be added and removed, even while the `Form` is showing. The order of items is important as well; most MIDP implementations will display a form's items top to bottom and possibly left to right, scrolling the form vertically as needed if there are more items than available screen space.

To add an `Item` to the bottom of a form, use one of the `append()` methods. The first one can be used to add any `Item` implementation. The second two `append()` methods are strictly for convenience; behind the scenes, a `StringItem` or an `ImageItem` will be created for you.

```
public int append(Item item)
public int append(String str)
public int append(Image image)
```

Every item in a form has an index. You can place an item at a specific index (replacing the previous item at that index) using the method:

```
public void set(int index, Item item)
```

Alternately, if you'd like to add an item somewhere in the middle of the form, just supply the desired index for the new item to the `insert()` method. Subsequent items will move up by one index.

```
public void insert(int index, Item item)
```

To remove an item from a form, use `delete()`.

```
public void delete(int index)
```

To remove all items with one call, use `deleteAll()`.

```
public void deleteAll()
```

If you forget what you put in a form, you can find out the number of items and retrieve them with the following methods:

```
public int size()
public Item get(int index)
```

Understanding Form Layout

MIDs can have very different screen size and shapes. Forms have support for very specific layout. There's an exhaustive description of the layout algorithm in the documentation for `javax.microedition.lcdui.Form`, in the section titled "Layout." Stated briefly, `Form` attempts to lay out items left-to-right in rows, stacking rows top-to-bottom, just like English text on a page. The `Item` class includes plumbing that allows some control over the layout of individual items.

The Item Pantry

The MIDP specification includes a handy toolbox of items that can be used to build forms. We'll cover each of them briefly in the following sections and show how some of them look in Sun's MIDP reference implementation.

The Item Class

All of the items that can be added to forms descend from the class `javax.microedition.lcdui.Item`. This class has a `getLabel()` and `setLabel()` method. All `Items` have a string label, although it may or may not be shown by the specific subclass.

`Items` can also have commands, just like `Displayables`. When an `Item` is selected in a form, the `Item`'s commands are shown along with the commands in the form. Figure 6-3 shows a form with four string items, cunningly named "one," "two," "three," and "four." The form itself has one command, "Exit." None of the string items has commands, except for "three," which has one command named "Details."

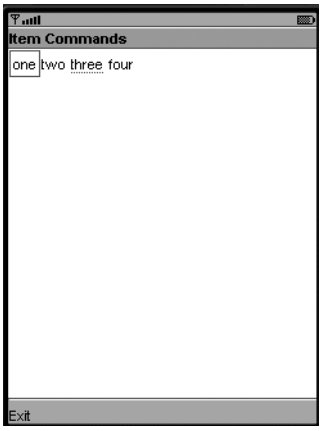


Figure 6-3. *Item "three" has a command.*

Note how the toolkit emulator indicates the presence of one or more commands on the item with a light underline. When you navigate through the form to the item with the additional command, it shows up just like any other command, as shown in Figure 6-4.

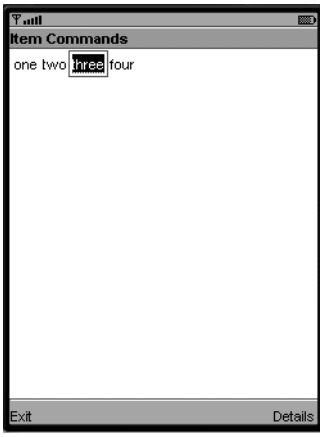


Figure 6-4. *When an item is selected, its commands are shown.*

The semantics for managing item commands are nearly identical to the semantics for managing form commands. You can manage the commands on an `Item` using `addCommand()` and `removeCommand()`. Note that the command type should be `ITEM` for commands added to `Item`, although no exception will be thrown if this is not true. A command listener may be assigned using the `setItemCommandListener()` method. The `ItemCommandListener` interface contains a single method, similar to `CommandListener`'s single method:

```
public void commandAction(Command c, Item item)
```

It's up to the implementation to figure out how to show commands for an item. All you do in a MIDlet is add commands, set a listener, and wait for command events.

`Items` also support a *default command*. This command may be invoked if the runtime device has a button or knob or other user interface control that is appropriate for a default command. You can set an `Item`'s default command by calling `setDefaultCommand()`.

`Item` has fields that are related to layout control. `Items` have a *minimum size* and a *preferred size* that can be used to control how large an item appears in a form. The minimum size is computed by the implementation and can be retrieved using `getMinimumWidth()` and `getMinimumHeight()`. The minimum size depends on the contents of the `Item` and can be changed by the implementation every time the contents change. There's no way to change an item's minimum size, but examining the minimum size may be useful to your application in deciding how to lay out a form.

The preferred size, by contrast, can either be computed by the implementation or specified by you. The default values for preferred width and height are `-1`, a special value that tells

the implementation, "I don't care, you go ahead and figure out the best size for this item." If you pass a specific positive value for the width or height in `setPreferredSize()`, that dimension is said to be *locked* and the implementation will attempt to use it during layout.

The `getPreferredWidth()` and `getPreferredHeight()` methods don't always return the values you've passed to `setPreferredSize()`. For example, if you've unlocked the width and height by calling `setPreferredSize(-1, -1)`, the values returned from `getPreferredWidth()` and `getPreferredHeight()` are the preferred sizes that the implementation has computed.

Finally, the `Item` class includes a layout directive, accessed using `getLayout()` and `setLayout()`. Represented by an integer, the layout value is usually a combination of `LAYOUT_2` with a horizontal value and a vertical value. `LAYOUT_2` is a flag to the implementation that the item should be laid out using MIDP 2 rules. The previous MIDP version (1.0) had very limited layout control capabilities. The horizontal values are

- `LAYOUT_LEFT`
- `LAYOUT_RIGHT`
- `LAYOUT_CENTER`

The vertical values are

- `LAYOUT_TOP`
- `LAYOUT_BOTTOM`
- `LAYOUT_VCENTER`

In addition, a layout value may include *shrinking* or *expanding*. Shrinking means that an item's minimum width or height is used, while expanding means that an item's size is stretched to fill the available width or row height. The constants for shrinking and expanding are

- `LAYOUT_SHRINK` (for width)
- `LAYOUT_EXPAND` (for width)
- `LAYOUT_VSHRINK` (for height)
- `LAYOUT_VEXPAND` (for height)

Finally, an `Item`'s layout may include a request for a new line before or after the item using the `LAYOUT_NEWLINE_BEFORE` or `LAYOUT_NEWLINE_AFTER` constants. `Items` are laid out in `Forms` much like text flows on a page, so these constants allow you to request a new row before or after an item.

Figure 6-5 shows a simple example, three components with the following layouts:

- `LAYOUT_2 | LAYOUT_LEFT | LAYOUT_NEWLINE_AFTER`
- `LAYOUT_2 | LAYOUT_CENTER | LAYOUT_NEWLINE_AFTER`
- `LAYOUT_2 | LAYOUT_RIGHT | LAYOUT_NEWLINE_AFTER`

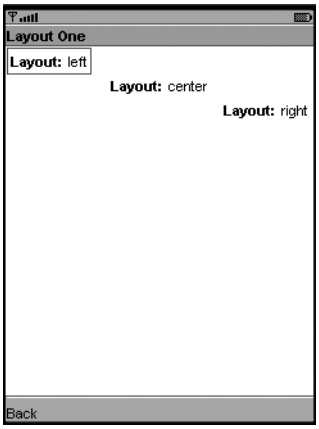


Figure 6-5. *Form layout example*

StringItem

`StringItem` represents a simple text label. For example, consider the following code:

```
Form form = new Form("Form Title");
StringItem stringItem = new StringItem("Label: ", "Value");
form.append(stringItem);
```

■ **Caution** You need to be careful when using a ":" in your `StringItem` labels. Some MIDP implementation may append its own ":" for a label, resulting in double colons. The MIDP implementation of the WTK emulator does not append colons automatically for `StringItem` labels.

The form produced by this code (plus a `Back` command) is shown in Figure 6-6.

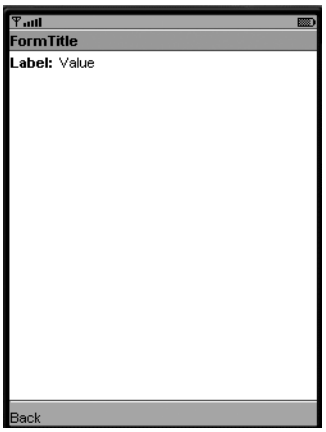


Figure 6-6. *A form with a single StringItem and a Back command*

You can use `null` for the `StringItem`'s label or value to indicate that it should not be shown on the screen. (Better yet, you could just use `Form`'s `append(String)` method.) `StringItem` inherits `setLabel()` and `getLabel()` methods from `Item`. It also includes `getText()` and `setText()` methods for accessing and adjusting the string value.

The appearance of both `StringItem` and `ImageItem` can be controlled using *appearance mode*. The appearance mode allows the item to look like a URL link or a button, although in all other respects the item behaves the same as a regular `StringItem` or `ImageItem`. The three appearance modes (which are defined in the `Item` class) are as follows:

- `PLAIN` shows the item in its normal state.
- `HYPERLINK` shows the item as a URL. A typical action would be to attempt to open the link using `MIDlet`'s `platformRequest()` method.
- `BUTTON` shows the item as a button. Note that this may be clumsy, especially on devices without pointer events, and you should generally use a `Command` where you feel tempted to use an item with a `BUTTON` appearance mode.

As with almost everything else in the `javax.microedition.lcdui` package, it's the implementation's responsibility to show different appearance modes, and your application may look different on different devices. Furthermore, it is your application's responsibility to implement appropriate behavior. For example, you might want to add a command to a `HYPERLINK StringItem` that calls `MIDlet`'s `platformRequest()` method to open the link.

■ **Note** The J2ME Wireless Toolkit emulators don't show `HYPERLINK` or `BUTTON StringItems` any differently from `PLAIN` ones, except for one special case. If the `StringItem` has a `BUTTON` type and it has an associated item command, it is shown with a beveled border.

Finally, there are also `getFont()` and `setFont()` methods in the `StringItem` class. We'll describe the `Font` class in Chapter 13.

Spacer

`Spacer` represents empty space in a `Form`. Unlike other `Items`, `Spacer` cannot gain focus and cannot have commands. It may be used for layout purposes. All you need to do is specify a minimum width and height:

```
public Spacer(minWidth, minHeight)
```

TextField

`TextField` represents an editable string. Figure 6-7 shows a `TextField` with a label of "TextFieldTitle" and a value of "text".

In Sun's MIDP emulator, text can be entered directly into a `TextField` either by clicking the number buttons in the emulator or by typing on the keyboard. Of course, it's up to the implementation to decide exactly how to allow editing. Some implementations may even show a separate screen for editing.

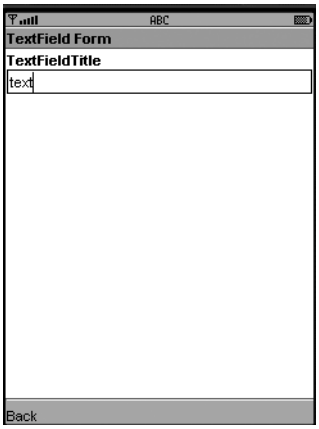


Figure 6-7. *A form with a single TextField and a Back command*

`TextFields` can limit input. The following constants are defined:

- `ANY` allows any type of input.
- `NUMERIC` restricts the input to numbers.
- `DECIMAL` allows numbers with fractional parts.
- `PHONENUMBER` requires a telephone number.
- `EMAILADDR` input must be an e-mail address.
- `URL` input must be a URL.

These input constraints might look familiar; they're the same ones used by `TextBox`, which we covered in the previous chapter. As with `TextBox`, the flags `PASSWORD`, `SENSITIVE`, `UNEDITABLE`, `NON_PREDICTIVE`, `INITIAL_CAPS_WORD`, and `INITIAL_CAPS_SENTENCE` can be combined with constraints using the `OR` operator.

To create a `TextField`, you need to supply the label, text value, maximum length, and input constraints.

```
public TextField(String label, String text, int maxSize, int constraints)
```

For an initially empty `TextField`, pass `null` for the `text` parameter.

As with `TextBox`, the `TextField` class includes a `setInitialInputMode()` method for suggesting to the implementation an appropriate input mode.

ImageItem

Forms can also contain images, which are represented by instances of `ImageItem`. `ImageItems` have several pieces of associated data:

- A *label* may be displayed with the image.
- The *layout* determines the placement of the image.
- *Alternate text* is displayed if the image cannot be shown.

To create an `ImageItem`, just supply the `Image` that is to be displayed, the label, layout, and alternate text.

`Layout` is controlled with the layout constants in the `Item` class. `ImageItem` also defines constants for the layout parameter. One way to control the layout is to specify the default value, `LAYOUT_DEFAULT`. If you need more control, combine a horizontal value with a vertical value. The horizontal values are `LAYOUT_LEFT`, `_LAYOUT_CENTER`, and `LAYOUT_RIGHT`. The vertical values are `LAYOUT_NEWLINE_BEFORE` and `LAYOUT_NEWLINE_AFTER`. The constants in the `ImageItem` class are present mainly for backward compatibility with older MIDP versions.

`ImageItem` supports appearance modes just like `StringItem`. `ItemItem` includes a constructor that allows you to set the appearance mode.

Figure 6-8 shows a form containing a single `ImageItem`.

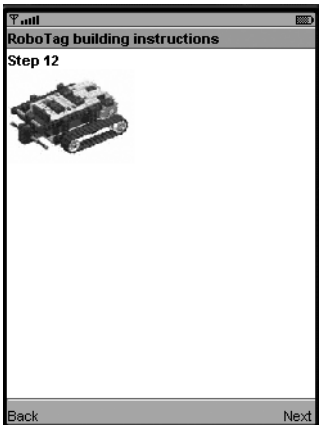


Figure 6-8. *An ImageItem*

DateField

`DateField` is an extremely handy mechanism by which users can enter dates, times, or both. It's up to the implementation to determine some reasonable way for users to enter dates and times; you, as the MIDlet programmer, simply use `DateField` and not worry about the implementation.

To create a `DateField`, specify a label and a type. Three constants in the `DateField` class describe the different types:

- `DATE` displays an editable date.
- `TIME` displays an editable time.
- `DATE_TIME` displays both a date and a time.

`DateField` provides two constructors. The first uses the default time zone, while the second allows you to specify a `TimeZone` explicitly:

```
public DateField(String label, int mode)
public DateField(String label, int mode, TimeZone timeZone)
```

In essence, a `DateField` is an editor for a `java.util.Date`. As you saw in Chapter 4, `Dates` represent points in time. `DateField` takes the role of translating between a `Date` and strings that humans can read, much like the `Calendar` class. You can set or get the `Date` represented by the `DateField` using the following methods:

```
public Date getDate()
public void setDate(Date date)
```

In the J2ME Wireless Toolkit emulator, a `DateField` appears as shown in Figure 6-9a. Note that if you do not supply a `Date` to `setDate()` before showing the `DateField`, it will appear uninitialized, as shown in Figure 6-9b.

When the user selects either the date or time portion of the `DateField` for editing, the MIDP implementation provides some kind of appropriate editor. Sun's emulator provides the editors shown in Figure 6-9c and Figure 6-9d.

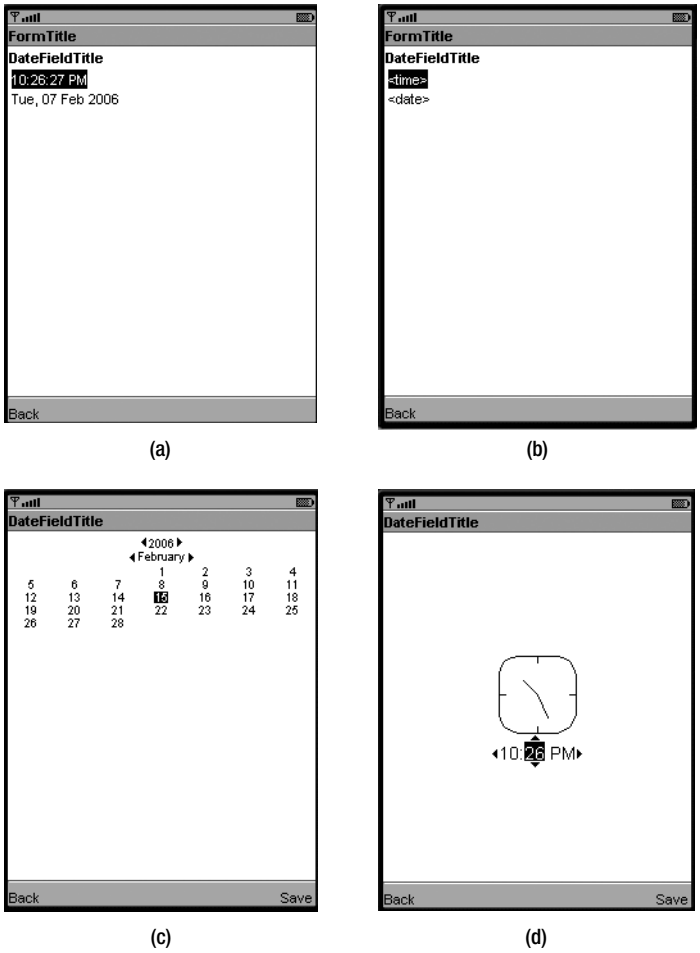


Figure 6-9. *DateField in Sun's MIDP 2.0 emulator*

Gauge

`Gauge` represents an integer value. It's up to the implementation of the `Gauge` class to decide how to display it. In Sun's MIDP implementation, `Gauge` appears as shown in Figure 6-10.

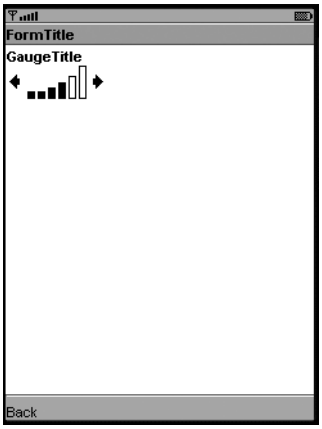


Figure 6-10. *A gauge*

The value of a `Gauge` instance can be retrieved and modified with the `getValue()` and `setValue()` methods. This value runs from 0 to a variable maximum value. The maximum for the gauge can be retrieved and modified with the `getMaxValue()` and `setMaxValue()` methods.

The visual appearance of the `Gauge` is an approximation of the gauge's value. The gauge shown in Figure 6-10 could, for example, have a value of 7 and a maximum of 10, or perhaps a value of 42 and a maximum of 61.

In an *interactive* gauge, the user can modify the value. Again, it's up to the implementation to decide exactly how this works. In Sun's reference implementation, the left and right navigation buttons can be used to modify a gauge's value.

`Gauge`'s constructor is straightforward:

```
public Gauge(String label, boolean interactive,
    int maxValue, int initialValue)
```

For example, the following code creates an interactive `Gauge` with a maximum value of 24 and an initial value of 2:

```
Gauge g = new Gauge("Power", true, 24, 2);
```

There are three varieties of noninteractive gauges that can be useful as progress indicators. You can use a regular noninteractive gauge with a known maximum value to show the progress of a download or a calculation. For example, if you were going to run through a loop 20 times, you could create a gauge with a maximum of 20 and update its value each time through the loop.

There are two kinds of noninteractive gauges with no maximum value. In this case, you use the special value `INDEFINITE` for the maximum. Such gauges can be either *incremental* or *continuous*. An incremental gauge shows an operation with measurable steps; your application will update the gauge every time it does something significant. For example, if you were downloading a file, but you didn't know how big it was, you could use an incremental gauge and

update the gauge whenever you read some data. A continuous gauge shows progress, probably using an animation, with no prodding needed from the application. This type of gauge is useful for operations where you can't measure the progress.

The gauge value itself can be set to one of the following:

- `INCREMENTAL_UPDATING` indicates that you have just accomplished something and the gauge should be updated to reflect it.
- `INCREMENTAL_IDLE` means that you want the gauge to be incremental but nothing is currently happening.
- `CONTINUOUS_RUNNING` indicates a continuous gauge in its running mode.
- `CONTINUOUS_IDLE` is used for a continuous gauge, indicating that no progress is currently being made.

The following example shows interactive, continuous, and incremental gauges. `Commands` (`Update` and `Idle`) set the appropriate values on the continuous and incremental gauges. Normally you would set these from separate threads, but using commands makes it easy to understand what's going on in this example.

In Sun's MIDP emulator, the continuous and idle gauges use simple Duke animations to show progress. See Figure 6-11 for a screen shot. Listing 6-2 contains the source code for a MIDlet that demonstrates different kinds of `Gauges`.

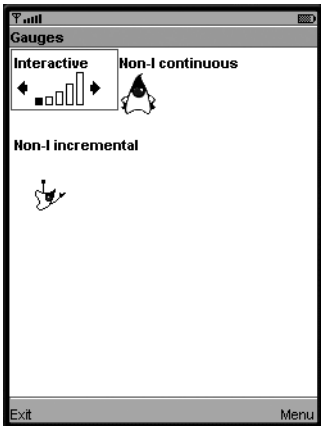


Figure 6-11. *Three kinds of Gauges in MIDP 2.0*

Listing 6-2. *GaugeMIDlet Source Code*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class GaugeMIDlet
    extends MIDlet
    implements CommandListener {
  private Display mDisplay;
```

```
private Form mGaugeForm;
private Command mUpdateCommand, mIdleCommand;

private Gauge mInteractiveGauge;
private Gauge mIncrementalGauge;
private Gauge mContinuousGauge;

public GaugeMIDlet() {
  mGaugeForm = new Form("Gauges");
  mInteractiveGauge = new Gauge("Interactive", true, 5, 2);
  mInteractiveGauge.setLayout(Item.LAYOUT_2);
  mGaugeForm.append(mInteractiveGauge);
  mContinuousGauge = new Gauge("Non-I continuous", false,
      Gauge.INDEFINITE, Gauge.CONTINUOUS_RUNNING);
  mContinuousGauge.setLayout(Item.LAYOUT_2);
  mGaugeForm.append(mContinuousGauge);
  mIncrementalGauge = new Gauge("Non-I incremental", false,
      Gauge.INDEFINITE, Gauge.INCREMENTAL_UPDATING);
  mIncrementalGauge.setLayout(Item.LAYOUT_2);
  mGaugeForm.append(mIncrementalGauge);

  mUpdateCommand = new Command("Update", Command.SCREEN, 0);
  mIdleCommand = new Command("Idle", Command.SCREEN, 0);
  Command exitCommand = new Command("Exit", Command.EXIT, 0);
  mGaugeForm.addCommand(mUpdateCommand);
  mGaugeForm.addCommand(mIdleCommand);
  mGaugeForm.addCommand(exitCommand);
  mGaugeForm.setCommandListener(this);
}

public void startApp() {
  if (mDisplay == null) mDisplay = Display.getDisplay(this);
  mDisplay.setCurrent(mGaugeForm);
}

public void pauseApp() {}

public void destroyApp(boolean unconditional) {}

public void commandAction(Command c, Displayable s) {
  if (c.getCommandType() == Command.EXIT)
    notifyDestroyed();
  else if (c == mUpdateCommand) {
    mContinuousGauge.setValue(Gauge.CONTINUOUS_RUNNING);
    mIncrementalGauge.setValue(Gauge.INCREMENTAL_UPDATING);
  }
```

```
    else if (c == mIdleCommand) {
      mContinuousGauge.setValue(Gauge.CONTINUOUS_IDLE);
      mIncrementalGauge.setValue(Gauge.INCREMENTAL_IDLE);
    }
  }
}
```

ChoiceGroup

Another class in the `Form` arsenal of `Items` is `ChoiceGroup`. `ChoiceGroup` offers a list of choices. It is very similar to `javax.microedition.lcdui.List`, which was described at the beginning of this chapter. This similarity is more than coincidental; `ChoiceGroup` and `List` both implement the `Choice` interface, which is the wellspring of all of the instance methods in both classes.

If you read the section about `List`, you already know almost everything you need to know to use `ChoiceGroup` because the instance methods work exactly the same way.

`ChoiceGroup` features the following constructors:

```
public ChoiceGroup(String label, int choiceType)
public ChoiceGroup(String label, int choiceType, String[] stringElements,
    Image[] imageElements)
```

The `choiceType` should look familiar; it can be either `EXCLUSIVE` or `MULTIPLE`, the constants defined in the `Choice` interface. In fact, `ChoiceGroup`'s constructors work exactly like `List`'s constructors, except that `IMPLICIT` is not allowed. This makes sense, since a `ChoiceGroup` is one item in a form, not an entire screen. There is also a `POPUP` type for `ChoiceGroup` that makes it appear like a combo box or a drop-down menu. The `ChoiceGroup` appears like any other element in the `Form`; Figure 6-12 shows examples.

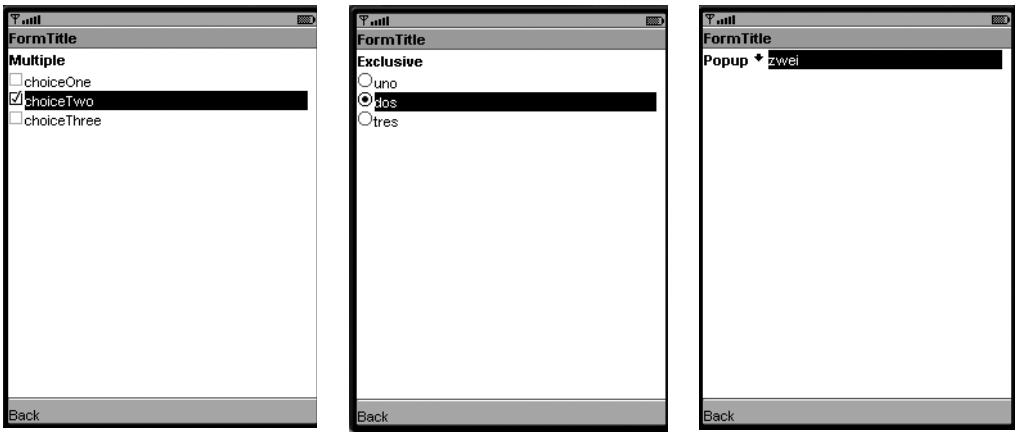


Figure 6-12. *ChoiceGroup examples: (a) MULTIPLE, (b) EXCLUSIVE, and (c) POPUP*

Responding to Item Changes

Most items in a `Form` fire events when the user changes them. Your application can listen for these events by registering an `ItemStateListener` with the `Form` using the following method:

```
public void setItemStateListener(ItemStateListener iListener)
```

`ItemStateListener` is an interface with a single method. This method is called every time an item in a `Form` is changed:

```
public void itemStateChanged(Item item)
```

Listing 6-3 creates a `Form` with two items, an interactive `Gauge` and a `StringItem`. As you adjust the `Gauge`, its value is reflected in the `StringItem` using the `ItemStateListener` mechanism.

Listing 6-3. *GaugeTracker Source Code*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class GaugeTracker
    extends MIDlet
    implements ItemStateListener, CommandListener {
  private Gauge mGauge;
  private StringItem mStringItem;

  public GaugeTracker() {
    int initialValue = 3;
    mGauge = new Gauge("GaugeTitle", true, 5, initialValue);
    mStringItem = new StringItem(null, "[value]");
    itemStateChanged(mGauge);
  }

  public void itemStateChanged(Item item) {
    if (item == mGauge)
      mStringItem.setText("Value = " + mGauge.getValue());
  }

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT)
      notifyDestroyed();
  }
```

```
  public void startApp() {
    Form form = new Form("GaugeTracker");
    form.addCommand(new Command("Exit", Command.EXIT, 0));
    form.setCommandListener(this);
    // Now add the selected items.
    form.append(mGauge);
    form.append(mStringItem);
    form.setItemStateListener(this);

    Display.getDisplay(this).setCurrent(form);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}
}
```

Summary

This chapter described MIDP's advanced user-interface screens, `List` and `Form`. A `List` is a list of elements that allows for single or multiple selections. You supply the items—it's up to the implementation to figure out how to show them, how the user navigates through them, and how the user selects items. `Forms` are generalized screens that are built up from a collection of `Items`. The MIDP API supplies a handy toolbox of `Items`—everything from simple string and image `Items` to the more complex `DateField` and `ChoiceGroup` classes.

Even though `List` and `Form` are very capable, you should use them sparingly, particularly `Form`. Small devices have small screens, so you don't want to put much information in each screen, especially if it's going to force the user to scroll up and down a lot. Furthermore, ease of use is crucial on consumer devices like mobile phones and pagers. Make sure your interface is clean, intuitive, and as simple as it can possibly be.

CHAPTER 7

Custom Items

In the last chapter, you learned about Forms, the most flexible and powerful descendents of javax.microedition.lcdui.Screen. Forms are essentially collections of Items. The MIDP APIs include a useful toolbox of Item subclasses, everything from text and image display to interactive date fields and gauges.

You can have even more power through the opportunity to define your own items. In this chapter, you'll learn how to create items that do their own drawing and respond to user input.

Introducing CustomItem

The class that makes custom items possible is appropriately named CustomItem. Like all items that live in a Form, it is a subclass of Item. To create your very own item, all you have to do is define a subclass of CustomItem by implementing five abstract methods. The first four, listed next, have to do with the size of the item's *content area*, which is the area for which your code has responsibility. The total area of the custom item includes a label and perhaps borders, but these are the responsibility of the implementation. Your CustomItem subclass is only responsible for the content area.

```
protected int getPrefContentWidth(int height)
protected int getPrefContentHeight(int width)
protected int getMinContentWidth()
protected int getMinContentHeight()
```

The first two methods should return values that define how big your item *wants* to be. When the MIDP implementation lays out a Form containing your item, it may not be able to honor your preferred size, but it will try. The implementation passes a proposed height and width into these methods to give your item class an idea of what its dimensions might eventually be. For example, the implementation might call your item's getPrefContentWidth() method and pass a value of 18 for the height parameter. This is the implementation asking your item, "What width would you like to be if I make your height 18?"

The second pair of methods should return information about the minimum size of the item. This is the smallest size that your item believes it can tolerate.

The fifth method that must be defined by a concrete CustomItem subclass is the paint() method, which the implementation calls to render the item.

```
protected void paint(Graphics g, int w, int h)
```

The Graphics object can be used to draw lines, shapes, text, and images on the content area of the item. The Graphics class is fully covered in Chapter 13; for now, we'll just use a few simple methods to demonstrate how to draw custom items. The w and h parameters indicate the current width and height of the content area.

Armed with this knowledge, you can create a simple CustomItem by implementing the five abstract methods described previously and providing a constructor. Listing 7-1 shows one such class, SimpleItem. This class returns hard-coded values for the minimum and preferred content dimensions and provides a paint() method that draws a simple pattern of triangles.

Listing 7-1. *A Simple Custom Item*

```
import javax.microedition.lcdui.*;

public class SimpleItem
    extends CustomItem {
  public SimpleItem(String title) { super(title); }

  // CustomItem abstract methods.

  public int getMinContentWidth() { return 100; }
  public int getMinContentHeight() { return 60; }

  public int getPrefContentWidth(int width) {
    return getMinContentWidth();
  }

  public int getPrefContentHeight(int height) {
    return getMinContentHeight();
  }

  public void paint(Graphics g, int w, int h) {
    g.drawRect(0, 0, w - 1, h - 1);
    g.setColor(0x000000ff);
    int offset = 0;
    for (int y = 4; y < h; y += 12) {
      offset = (offset + 12) % 24;
      for (int x = 4; x < w; x += 24) {
        g.fillTriangle(x + offset,     y,
                       x + offset - 3, y + 6,
                       x + offset + 3, y + 6);
      }
    }
  }
}
```

We won't make you write your own MIDlet to see your new item. Listing 7-2 shows a MIDlet that uses SimpleItem.

Listing 7-2. *A MIDlet That Demonstrates SimpleItem*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class SimpleItemMIDlet
    extends MIDlet
    implements CommandListener {
  public void startApp() {
    Form form = new Form("SimpleItemMIDlet");
    form.append(new SimpleItem("SimpleItem"));

    Command c = new Command("Exit", Command.EXIT, 0);
    form.addCommand(c);
    form.setCommandListener(this);

    Display.getDisplay(this).setCurrent(form);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT)
      notifyDestroyed();
  }
}
```

Figure 7-1 shows this MIDlet in action.

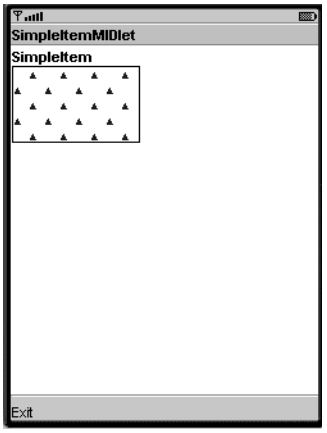


Figure 7-1. *A simple custom item*

CustomItem Painting

As you've seen, a `CustomItem` is drawn on the screen in its `paint()` method. This method is passed a `Graphics` object that serves two purposes. First, it represents the drawing surface of the `CustomItem`'s content area. Second, it provides numerous methods for drawing shapes, images, and text. We won't cover all of these methods until Chapter 13, but you'll see a couple of them in the examples in this chapter: for instance, `drawString()` renders text, while `drawLine()` renders a straight line.

The `paint()` method is an example of a *callback*, a method in your code that is called by the MIDP implementation. The implementation calls `paint()` whenever it needs to show your custom item on the screen. It calls other methods to find out the minimum and preferred sizes of your component when its containing form is being laid out. It's the implementation's job to show the whole screen; it just calls your `paint()` method to show the part of the screen occupied by your custom item. You don't tell the implementation when to draw your item; you just tell it that your item is part of a form, and then it figures out how to show everything.

If something needs to change in your custom item's appearance, you can request a refresh by calling the `repaint()` method. This method signals to the implementation that your item needs to be drawn. In response, the implementation will soon call the `paint()` method again. For optimized drawing, you may only wish to redraw part of the item. In this case, use `repaint(int x, int y, int width, int height)` to describe a rectangular region of the item that needs to be drawn.

Two methods return information that can help you make your item's appearance consistent with the device's look and feel. The first is `getColor()` in the `Display` class. This method returns an `int` representing a color when you supply one of the following constants:

- `COLOR_BACKGROUND`
- `COLOR_BORDER`
- `COLOR_FOREGROUND`
- `COLOR_HIGHLIGHTED_BACKGROUND`
- `COLOR_HIGHLIGHTED_BORDER`
- `COLOR_HIGHLIGHTED_FOREGROUND`

For example, you could set the current drawing color to the system's highlighted foreground color with the following code:

```
public void paint(Graphics g) {
  // Display mDisplay = ...
  int fhc = mDisplay.getColor(
      Display.COLOR_HIGHLIGHTED_FOREGROUND);
  g.setColor(fhc);
  // Draw stuff ...
}
```

Similarly, if you want any text drawn by your custom item to harmonize with other items in a `Form`, you can retrieve an appropriate `Font` using the following method in the `Font` class:

```
public static Font getFont(int fontSpecifier)
```

Just pass either FONT_STATIC_TEXT or FONT_INPUT_TEXT and this method returns an appropriate Font object that you can use for drawing text. The following code shows how to use an appropriate font for drawing user-editable text:

```
public void paint(Graphics g) {
  Font f = Font.getFont(Font.FONT_INPUT_TEXT);
  g.setFont(f);
  // Draw text ...
}
```

We'll cover Font in detail in Chapter 13. In brief, a Font determines the appearance of text that is drawn on the screen.

Showing, Hiding, and Sizing

When a CustomItem is made visible, even partially visible, its showNotify() method is called by the MIDP implementation. You can expect subsequent calls to paint() to render the item. Similarly, hideNotify() is called when the item is no longer visible (if the user has scrolled the item off the screen, for example).

The size of your custom item may be changed by the implementation, perhaps if the containing Form gets laid out again in response to changing content. In this case, your item's sizeChanged() method is called with the new width and height of the content area.

Similarly, your custom item may decide that it needs to be a different size. In this case, your item should call the invalidate() method, which signals the implementation that it may need to lay out the containing Form again.

Handling Events

A CustomItem can respond to keyboard and pointer events by overriding any or all of the following methods:

```
protected void keyPressed(int keyCode)
protected void keyReleased(int keyCode)
protected void keyRepeated(int keyCode)
protected void pointerPressed(int x, int y)
protected void pointerReleased(int x, int y)
protected void pointerDragged(int x, int y)
```

These methods are called in response to the user's actions. The keyCode parameter will most likely be one of the constants defined in the Canvas class: KEY_NUM0 through KEY_NUM9, KEY_POUND, or KEY_STAR. The CustomItem class also supports a handy mechanism called *game actions*, which maps device-specific keys to device-independent actions. The getGameAction() method performs this mapping. For a full discussion of game actions, see Chapter 13.

The pointer callback methods supply the location of the pointer event as a pair of coordinates relative to the custom item's content area.

Devices have varying capabilities, and some may not be able to deliver certain types of events to CustomItems. Many phones, for example, will not support pointer events. To find out the capabilities of the device at runtime, custom items use the getInteractionModes() method. This method returns some combination of the following constants (defined in CustomItem):

- KEY_PRESS
- KEY_RELEASE
- KEY_REPEAT
- POINTER_PRESS
- POINTER_RELEASE
- POINTER_DRAG
- TRAVERSE_HORIZONTAL
- TRAVERSE_VERTICAL

Except for the traversal items (which are covered in the next section), the combination of values returned from `getInteractionModes()` corresponds directly to which callbacks are likely to be invoked in your custom item. You can use this information to build a `CustomItem` that will work under any circumstances. For example, in the unlikely event that a device was unable to deliver both key and pointer events to a custom item, you could supply a `Command` on the item to invoke a separate editing screen.

Item Traversal

`Forms` support a concept of *focus*, where one item in the form is currently selected. *Traversal* refers to the user being able to shift focus from one item to another. In most cases, the MIDP implementation handles the details of `Form` traversal. In the Sun emulator, for example, you can move the focus through the items in a form by pressing the up and down keys. Focus is indicated by a solid black border around an item. Figure 7-2 shows a form with several items; the third item, an `ImageItem`, has the focus.

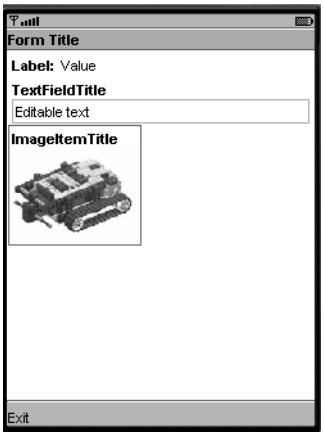


Figure 7-2. *The focus is on the third item in this form.*

So far, so good—this is all pretty straightforward. As a matter of fact, the default implementation provided in `CustomItem` means you don't even have to think about traversal in many cases.

What makes things a little wonky is the concept of *internal* traversal. Some items support traversal of multiple choices *inside* the item. A good example is the `ChoiceGroup` item. The following sequence shows traversal through a form with three items in the MIDP reference implementation emulator. Figure 7-3 shows the traversal progressing from the text field through the gauge and into the `ChoiceGroup`.

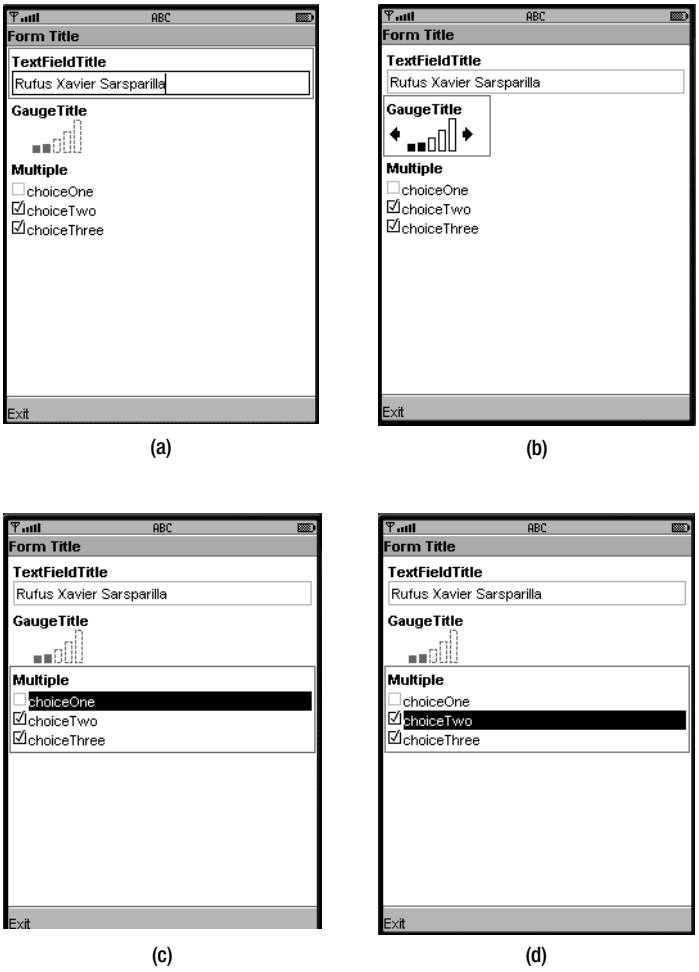


Figure 7-3. *Form traversal and internal item traversal*

Two methods signal traversal events. The first, `traverse()`, is called the first time the user traverses into the item. By default this method returns `false`, indicating that the item does not support internal traversal. The second method, `traverseOut()`, is called whenever the user leaves the item.

```
protected boolean traverse(int dir, int viewportWidth, int viewportHeight,
       int[] visRect_inout);
protected void traverseOut();
```

■ **Note** At first glance, you might expect custom items to receive calls on both the traversal methods and the key event methods when keys are pressed on the device. For example, if the user presses the down arrow key to move into the item, you might expect both the `traverse()` and `keyPressed()` methods to be called. In reality, the implementation should keep key events and traversal events unambiguous. Bear in mind that some devices will have alternate traversal controls (wheels, for example), so the implementation (and your custom item) should treat the events distinctly.

If you do write a custom item that supports internal traversal, you need to pay attention to the arguments passed to `traverse()` and you need to return `true` to indicate that your item supports internal traversal. The information passed to the `traverse()` method is as follows:

- `dir` indicates the traversal direction requested by the user. It is one of the following: `Canvas.UP`, `Canvas.DOWN`, `Canvas.LEFT`, `Canvas.RIGHT`, or `CustomItem.NONE`.
- `viewportWidth` and `viewportHeight` indicate the size available for items in the `Form` containing this custom item. (In essence, `viewportWidth` and `viewportHeight` describe the content area of the `Form`.) These dimensions may be useful for determining the relationship between an item's choices and the amount of available screen area.
- `visRect_inout` is kind of weird. It is an integer array with four elements. When the `traverse()` method is called, `visRect_inout` describes the region of the custom item's visible content area. When the `traverse()` method returns, `visRect_inout` should contain the bounds of the currently selected choice in the item.

If this is starting to sound a little hairy, just wait. The traversal mechanism is flexible enough to support different kinds of traversal. Some devices may only be able to support vertical traversal, while others may only support horizontal, and still others may support both. You can find out the device's traversal capabilities with the `getInteractionModes()` method, which can return `CustomItem.TRAVERSE_HORIZONTAL`, `CustomItem.TRAVERSE_VERTICAL`, or both. Depending on the nature of the choices contained in your custom item, you may have to be flexible about the traversal directions you're receiving and the actual traversal inside the item.

Remember, the `traverse()` method is called when focus first comes to your item. If this method returns `true`, `traverse()` will be repeatedly called while traversal progresses through your item. When the user traverses out of your item, return `false` from the `traverse()` method. This lets the implementation know that internal traversal has ended. Most likely the implementation will call `traverseOut()`, although this only happens if focus actually moves away from the item. This may not be the case if the user has reached the end or beginning of the form.

All of this is discussed in meticulous detail in the API documentation for `CustomItem`'s `traverse()` method. If you're planning to implement a custom item with internal traversal, go read the documentation a few times until it all sinks in.

An Example

In this section, we'll show you `StationSign`, a `CustomItem` of medium complexity. `StationSign` has the following features:

- Implements a simple scrolling list of string choices. Pointer events and key events cause the current selection to move to the next choice. The scrolling is animated. `StationSign` is a `Runnable`—a separate thread is created in the constructor and used to call the `run()` method. If there's a difference between the current display state of the item and the current selection, `run()` reconciles the two by scrolling.
- Conforms to the device's look and feel by using the font for static text and colors returned from `Display`'s `getColor()` method.
- Does not implement internal traversal.
- Uses the `traverse()` and `traverseOut()` methods to recognize focus and paint using highlight colors. When `traverse()` is called, `StationSign` sets a `boolean` member variable, `mFocus`, to indicate that the item has focus. In the `paint()` method, `mFocus` is used to determine what colors are used to draw the item. When `traverseOut()` is called, `mFocus` is set to `false`, indicating that focus has been lost.

The entire source code for `StationSign` is shown in Listing 7-3.

Listing 7-3. *The StationSign Custom Item*

```
import java.util.Vector;

import javax.microedition.lcdui.*;

public class StationSign
    extends CustomItem
    implements Runnable {
  private Vector mValues;
  private int mSelection;
  private boolean mTrucking;

  private Display mDisplay;
  private Font mFont;
  private int mVisibleIndexTimesTen;
  private boolean mFocus;

  public StationSign(String title, Display display) {
    super(title);
    mDisplay = display;
    mValues = new Vector();
    mSelection = 0;
    mTrucking = true;
    mFont = Font.getFont(Font.FONT_STATIC_TEXT);
    mVisibleIndexTimesTen = mSelection * 10;
```

```
    Thread t = new Thread(this);
    t.start();
  }

  public void add(String value) {
    if (value == null) return;
    mValues.addElement(value);
  }

  public void remove(String value) {
    if (value == null) return;
    mValues.removeElement(value);
  }

  public String getSelection() {
    if (mValues.size() == 0) return "";
    return (String)mValues.elementAt(mSelection);
  }

  public void flip() {
    mSelection++;
    if (mSelection >= mValues.size()) mSelection = 0;
  }

  public void dispose() {
    mTrucking = false;
  }

  // Runnable interface.

  public void run() {
    while (mTrucking) {
      int target = mSelection * 10;
      if (mVisibleIndexTimesTen != target) {
        mVisibleIndexTimesTen++;
        if (mVisibleIndexTimesTen >= mValues.size() * 10)
          mVisibleIndexTimesTen = 0;
        repaint();
      }
      try { Thread.sleep(50); }
      catch (InterruptedException ie) {}
    }
  }

  // CustomItem abstract methods.
```

```
public int getMinContentWidth() {
  // Loop through the values. Find the maximum width.
  int maxWidth = 0;
  for (int i = 0; i < mValues.size(); i++) {
    String value = (String)mValues.elementAt(i);
    int width = mFont.stringWidth(value);
    maxWidth = Math.max(maxWidth, width);
  }
  // Don't forget about the title, although we don't
  // really know what font is used for that.
  int width = mFont.stringWidth(getLabel()) + 20;
  maxWidth = Math.max(maxWidth, width);
  return maxWidth;
}

public int getMinContentHeight() {
  return mFont.getHeight();
}

public int getPrefContentWidth(int width) {
  return getMinContentWidth();
}

public int getPrefContentHeight(int height) {
  return getMinContentHeight();
}

public void paint(Graphics g, int w, int h) {
  int fraction = mVisibleIndexTimesTen % 10;
  int visibleIndex = (mVisibleIndexTimesTen - fraction) / 10;
  String value = (String)mValues.elementAt(visibleIndex);

  g.setFont(mFont);
  int bc = mDisplay.getColor(Display.COLOR_BACKGROUND);
  int fc = mDisplay.getColor(Display.COLOR_FOREGROUND);
  if (mFocus == true) {
    bc = mDisplay.getColor(Display.COLOR_HIGHLIGHTED_BACKGROUND);
    fc = mDisplay.getColor(Display.COLOR_HIGHLIGHTED_FOREGROUND);
  }
  g.setColor(bc);
  g.fillRect(0, 0, w, h);
  g.setColor(fc);

  // Simple case: visibleIndex is aligned on a single item.
  if (fraction == 0) {
    g.drawString(value, 0, 0, Graphics.TOP | Graphics.LEFT);
    return;
  }
```

```
    // Complicated case: show two items and a line.
    int lineHeight = mFont.getHeight();
    int divider = lineHeight - lineHeight * fraction / 10;

    // Draw the piece of the visible value.
    g.drawString(value, 0, divider - lineHeight,
        Graphics.TOP | Graphics.LEFT);
    // Now get the next value.
    visibleIndex = (visibleIndex + 1) % mValues.size();
    value = (String)mValues.elementAt(visibleIndex);

    // Draw the line.
    g.setStrokeStyle(Graphics.DOTTED);
    g.drawLine(0, divider, w, divider);

    g.drawString(value, 0, divider,
        Graphics.TOP | Graphics.LEFT);
  }

  // CustomItem methods.

  protected void keyPressed(int keyCode) { flip (); }

  protected void pointerPressed(int x, int y) { flip(); }

  protected boolean traverse(int dir,
      int viewportWidth, int viewportHeight,
      int[] visRect_inout) {
    mFocus = true;
    repaint();
    return false;
  }

  protected void traverseOut() {
    mFocus = false;
    repaint();
  }
}
```

The MIDlet in Listing 7-4 displays a form that contains a `StationSign`.

Listing 7-4. *A MIDlet That Demonstrates StationSign*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class StationSignMIDlet
    extends MIDlet
    implements CommandListener {
  public void startApp() {
    Display display = Display.getDisplay(this);


    Form form = new Form("StationSignMIDlet");
    form.append(new StringItem("StringItem: ", "this is the first item "));
    StationSign ss = new StationSign("Destination", display);
    ss.add("Albuquerque");
    ss.add("Savannah");
    ss.add("Pocatello");
    ss.add("Des Moines");
    form.append(ss);
    form.append(new StringItem("StringItem: ", "this is item two"));

    Command c = new Command("Exit", Command.EXIT, 0);
    form.addCommand(c);
    form.setCommandListener(this);

    display.setCurrent(form);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT)
      notifyDestroyed();
  }
}
```

The MIDlet in action appears in Figure 7-4. The figure shows an instance of `StationSign` sandwiched between two `StringItems`. You can navigate through the form to see how the appearance of `StationSign` changes when it has input focus. If you click the select button on `StationSign`, you'll see the next choice scroll into view.

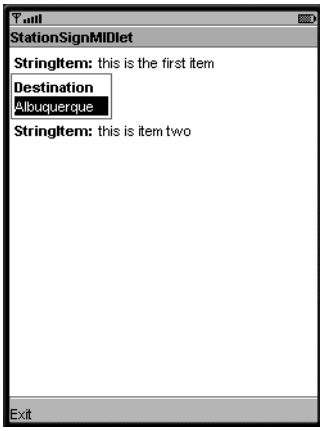


Figure 7-4. *StationSign in action in a Form*

Summary

This chapter described MIDP's support for custom items. The `CustomItem` class is the basis of items you can write to include in `Forms`. You can determine the custom item's appearance in the `paint()` method by drawing using a `Graphics` object. Callback methods throughout `CustomItem` let you know when the item is shown or hidden and deliver key, pointer, and traversal events. Two examples, `SimpleItem` and `StationSign`, provided a foundation of working code that you can adapt to build your own items.

A word of caution is appropriate here. While custom items allow almost unlimited flexibility for creating new `Form` items, it is quite difficult to create a `CustomItem` that has a consistent look and feel with the rest of the standard MIDP `Form` items. Testing can be intensive if the final application has to run across different devices with different MIDP implementations.

CHAPTER 8

Persistent Storage I: MIDP Record Store

MIDP applications have to run seamlessly on many devices. You've already seen how this can be a challenge in the user interface arena. The trick there was to use abstract concepts that would be mapped to the screen by a device-specific implementation.

MIDP's approach to persistent storage is basically the same. Your application could run on a device with flash ROM or battery-backed RAM. MIDP applications don't really care; all they know about are small databases called record stores. It's up to the device's MIDP implementation to map record stores in some reasonable manner to whatever persistent storage is available.

These are *small* amounts of data we're talking about; the MIDP specification dictates that the minimum amount of persistent storage is only 8KB. The record store mechanism is highly effective for these small amounts of persistent storage.

Overview

In MIDP, persistent storage is centered around record stores. A *record store* is a small database that contains pieces of data called *records*. Record stores are represented by instances of `javax.microedition.rms.RecordStore`. The scope of a record store can either be limited to a single MIDlet suite or be shared between MIDlet suites. Said another way, you can either restrict a MIDlet to only access record stores that were created by a MIDlet in the same suite, or you can explicitly allow MIDlets from multiple suites to share a record store . Figure 8-1 shows the relationship between MIDlet suites and record stores.

Record stores are identified by a name. Within a MIDlet suite's record stores, the names must be unique.

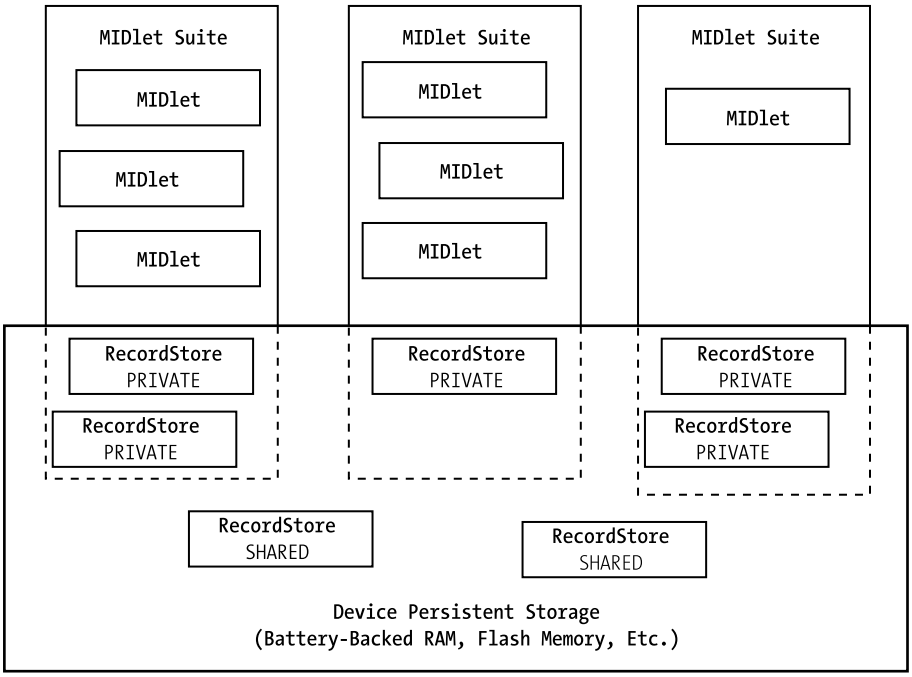


Figure 8-1. *Private and shared record stores between MIDlet suites*

Managing Record Stores

The `RecordStore` class serves two purposes. First, it defines an API for manipulating individual records. Second, it defines an API (mostly static methods) for managing record stores.

Opening, Closing, and Removing Record Stores

To open a record store, you simply need to name it.

```
public static RecordStore openRecordStore(String recordStoreName,
    boolean createIfNecessary) throws RecordStoreException,
    RecordStoreFullException, RecordStoreNotFoundException
```

If the record store does not exist, the `createIfNecessary` parameter determines whether a new record store will be created or not. If the record store does not exist, and the `createIfNecessary` parameter is `false`, then a `RecordStoreNotFoundException` will be thrown.

The following code opens a record store named "Address":

```
RecordStore rs = RecordStore.openRecordStore("Address", true);
```

The record store will be created if it does not already exist.

An open record store can be closed by calling the `closeRecordStore()` method. As with anything that can be opened and closed, it's a good idea to close record stores when you're finished with them. Memory and processing power are in short supply on a small device, so

you should remember to clean up after yourself as much as possible. You probably shouldn't even keep a record store open over the lifetime of the MIDlet; after all, your MIDlet may be paused by the device's application manager, and it would be unwise to have open resources while the MIDlet is paused.

To find out all the record stores available to a particular MIDlet suite, call the `listRecordStores()` method:

```
public static String[] listRecordStores()
```

Finally, to remove a record store, call the static `deleteRecordStore()` method. The record store and its contained records will be deleted.

■ **Note** Record store operations, particularly opening and closing, may be time-consuming on actual devices. You probably won't notice the delays using a desktop MIDP emulator, but on a real device, it may slow down applications noticeably. (See `http://www.poqit.com/midp/bench/` for some sobering measurements from real devices.) For many applications, it may be appropriate to place record store access in its own thread, just as network access goes in its own thread.

An additional consideration is that frequent read/write operations to the RMS can cause quite a drain on the battery. A useful strategy for avoiding this problem is to cache records in memory and only write to the actual persistent storage when a record is modified.

Sharing Record Stores

Record stores also have an authorization mode. The default authorization mode is `AUTHMODE_PRIVATE`, which means that a record store is only accessible from MIDlets in the MIDlet suite that created the record store. This is exactly as described earlier.

Record stores can be shared by changing their authorization mode to `AUTHMODE_ANY`, which means that any other MIDlet on the device can access the record store. Be careful with this! Don't put any secrets in an `AUTHMODE_ANY` record store. In addition, you can decide if you want a shared record store to be writable or read-only.

You can create a shared record store using an alternate `openRecordStore()` method in the `RecordStore` class:

```
public static RecordStore openRecordStore(String recordStoreName,
    boolean createIfNecessary, byte authMode, boolean writable)
    throws RecordStoreException, RecordStoreFullException,
    RecordStoreNotFoundException
```

The `authMode` and `writable` parameters are only used if the record store is created, which implies that the record store doesn't exist and `createIfNecessary` is `true`. You can change the authorization mode and writable flag of an open record store using the following method:

```
public void setMode(byte authmode, boolean writable)
    throws RecordStoreException
```

Note that only a MIDlet belonging to the suite that created the record store can change its authorization mode and writable flag.

How do you access a shared record store? One final `openRecordStore()` method provides the answer:

```
public static RecordStore openRecordStore(String recordStoreName,
    String vendorName, String suiteName)
    throws RecordStoreException, RecordStoreNotFoundException
```

To access a shared record store, you need to know its name, the name of the MIDlet suite that created it, and the name of the MIDlet suite's vendor. These names must be the `MIDlet-Name` and `MIDlet-Vendor` attributes in the MIDlet suite JAR manifest or the application descriptor.

Record Store Size

Record stores consist of records; each record is simply an array of bytes. On space-constrained devices, you'll probably want to keep a close eye on the size of your record stores. To find out the number of bytes used by a record store, call the following method on a `RecordStore` instance:

```
public int getSize()
```

You can find out how much more space is available by calling the following method:

```
public int getSizeAvailable()
```

Note that this method returns the total space available in the record store, which is not the same as the amount of record data that is available. That is, there is some overhead associated with each record in the record store; the `getSizeAvailable()` method returns the amount of space available for both record data and overhead.

Version and Timestamp

Record stores maintain both a version number and a timestamp. The version number is updated every time the record store is modified. It is represented by an integer and can be retrieved by calling `getVersion()`.

The record store also remembers the last time it was modified. This moment in time is represented by a `long`, which can be retrieved with `getLastModified()`. The long represents the number of milliseconds since midnight on January 1, 1970. You may recall (from Chapter 4) that this is the same way that `Date` uses a `long` to represent a moment in time. If you need to examine the timestamp of a record store, you can create a `Date` from the `long` timestamp. Then you could use a `Calendar` to translate from a `Date` to calendar fields like month, day, hour, and minute.

Working with Records

A *record* is simply an array of bytes. Each record in a `RecordStore` has an integer identification number. Figure 8-2 shows a diagram of a `RecordStore` with four records.

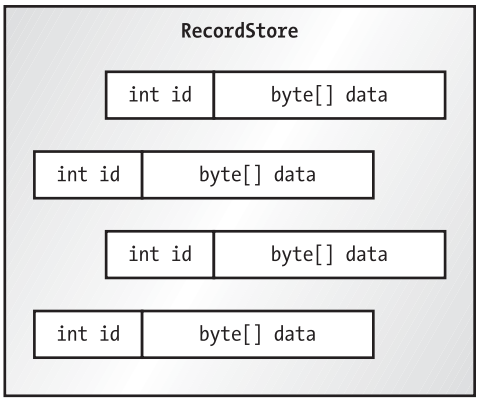


Figure 8-2. *Inside a RecordStore*

Adding Records

To add a new record, supply the byte array to the `addRecord()` method:

```
public int addRecord(byte[] data, int offset, int numBytes)
    throws RecordStoreNotOpenException,
           RecordStoreException,
           RecordStoreFullException
```

The added record will be `numBytes` long, taken from the `data` array starting at `offset`. The new record's ID is returned. Most other record operations need this ID to identify a particular record.

There's no explicit maximum record length, although, of course, there will be limits based on the amount of space that is available on the device for record stores.

The following code fragment illustrates adding a new record to a record store named `rs`. It creates a byte array from a `String`, and then writes the entire byte array into a new record.

```
String record = "This is a record";
byte[] data = record.getBytes();
int id = rs.addRecord(data, 0, data.length);
```

Retrieving Records

You can retrieve a record by supplying the record ID to the following method:

```
public byte[] getRecord(int recordId)
    throws RecordStoreNotOpenException,
           InvalidRecordIDException,
           RecordStoreException
```

This method returns a freshly created byte array containing the record with the requested ID. An alternate version of this method puts the record data into an array that you supply:

```
public int getRecord(int recordId, byte[] buffer, int offset)
    throws RecordStoreNotOpenException,
           InvalidRecordIDException,
           RecordStoreException
```

This method returns the number of bytes that were copied into your array. If the array you supply is not large enough to hold the record, an `ArrayOutOfBoundsException` will be thrown. You can find out the size of a particular record ahead of time by calling `getRecordSize()`.

Given a `RecordStore rs` and a record ID `id`, here is one way to retrieve a record's data:

```
byte[] retrieved = new byte[rs.getRecordSize(id)];
rs.getRecord(id, retrieved, 0);
String retrievedString = new String(retrieved);
```

If you're going to be pulling many records out of the record store, you probably won't want to create a new byte array each time. For efficiency, you would create one array and use it over and over again to pull records out of the record store. One way to create the buffer is to make it as large as the largest record in the record store. If that's not practical, or if you don't know how large the largest record will be, you can simply check the size of each record before you retrieve it. If you come across a record that's larger than the buffer, you could create a larger buffer.

If you're not worried about memory usage or speed, then you might as well use the other form of `getRecord()`, which is essentially the same as the previous code example:

```
byte[] retrieved = rs.getRecord(id);
```

Deleting and Replacing Records

So far you've seen how to add new records and retrieve them. There are two more record operations supported by `RecordStore`. First, you can remove a record by passing its ID to `deleteRecord()`. Second, you can replace the data of an existing record by calling the following method:

```
public void setRecord(int recordId, byte[] newData, int offset, int numBytes)
    throws RecordStoreNotOpenException,
           InvalidRecordIDException,
           RecordStoreException,
           RecordStoreFullException
```

Getting RecordStore Record Information

The `RecordStore` keeps an internal counter that it uses to assign record IDs. You can find out what the next record ID will be by calling `getNextRecordID()`. And you can find out how many records exist in the `RecordStore` by calling `getNumRecords()`.

Saving User Preferences

Let's put some of this knowledge to work. This section details a simple MIDlet that saves a user name and password in a `RecordStore`. Each time the MIDlet is used, it can load the user name

and password from the `RecordStore` instead of requiring the user to enter the same information over and over.

The MIDlet itself is very simple. Its only screen is a `Form` that contains fields for entering the user name and password. It uses a helper class, `Preferences`, to do all the `RecordStore` work. Listing 8-1 shows the source code for the MIDlet.

Listing 8-1. *Source Code for RecordMIDlet*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;
import javax.microedition.rms.RecordStoreException;

public class RecordMIDlet
    extends MIDlet
    implements CommandListener {
  private static final String kUser = "user";
  private static final String kPassword = "password";

  private Preferences mPreferences;
  private Form mForm;
  private TextField mUserField, mPasswordField;

  public RecordMIDlet() {
    try {
      mPreferences = new Preferences("preferences");
    }
    catch (RecordStoreException rse) {
      mForm = new Form("Exception");
      mForm.append(new StringItem(null, rse.toString()));
      mForm.addCommand(new Command("Exit", Command.EXIT, 0));
      mForm.setCommandListener(this);
      return;
    }

    mForm = new Form("Login");
    mUserField = new TextField("Name",
        mPreferences.get(kUser), 32, 0);
    mPasswordField = new TextField("Password",
        mPreferences.get(kPassword), 32, 0);
    mForm.append(mUserField);
    mForm.append(mPasswordField);

    mForm.addCommand(new Command("Exit", Command.EXIT, 0));
    mForm.setCommandListener(this);
  }
```

```
  public void startApp() {
    Display.getDisplay(this).setCurrent(mForm);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {
    // Save the user name and password.
    mPreferences.put(kUser, mUserField.getString());
    mPreferences.put(kPassword, mPasswordField.getString());
    try { mPreferences.save(); }
    catch (RecordStoreException rse) {}
  }

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT) {
      destroyApp(true);
      notifyDestroyed();
    }
  }
}
```

All the `RecordStore` work is encapsulated in the `Preferences` class shown in Listing 8-2. `Preferences` is a wrapper for a map of string keys and values, stored internally as `mHashtable`. When a `Preferences` object is created, key and value pairs are loaded from the record store. A key and value pair is stored in a single record using a pipe character separator (`|`).

`Preferences` uses a `RecordEnumeration` to walk through all the records in the record store. We'll talk about `RecordEnumeration` soon; for now, just trust us when we tell you it gives you a way to paw through the data in the record store.

Listing 8-2. *A Class That Encapsulates RecordStore Access*

```
import java.util.*;
import javax.microedition.lcdui.*;
import javax.microedition.rms.*;

public class Preferences {
  private String mRecordStoreName;

  private Hashtable mHashtable;

  public Preferences(String recordStoreName)
      throws RecordStoreException {
    mRecordStoreName = recordStoreName;
    mHashtable = new Hashtable();
    load();
  }
```

```
public String get(String key) {
  return (String)mHashtable.get(key);
}

public void put(String key, String value) {
  if (value == null) value = "";
  mHashtable.put(key, value);
}

private void load() throws RecordStoreException {
  RecordStore rs = null;
  RecordEnumeration re = null;

  try {
    rs = RecordStore.openRecordStore(mRecordStoreName, true);
    re = rs.enumerateRecords(null, null, false);
    while (re.hasNextElement()) {
      byte[] raw = re.nextRecord();
      String pref = new String(raw);

      // Parse out the name.
      int index = pref.indexOf('|');
      String name = pref.substring(0, index);
      String value = pref.substring(index + 1);
      put(name, value);
    }
  }
  finally {
    if (re != null) re.destroy();
    if (rs != null) rs.closeRecordStore();
  }
}

public void save() throws RecordStoreException {
  RecordStore rs = null;
  RecordEnumeration re = null;
  try {
    rs = RecordStore.openRecordStore(mRecordStoreName, true);
    re = rs.enumerateRecords(null, null, false);

    // First remove all records, a little clumsy.
    while (re.hasNextElement()) {
      int id = re.nextRecordId();
      rs.deleteRecord(id);
    }
```

```
      // Now save the preferences records.
      Enumeration keys = mHashtable.keys();
      while (keys.hasMoreElements()) {
        String key = (String)keys.nextElement();
        String value = get(key);
        String pref = key + "|" + value;
        byte[] raw = pref.getBytes();
        rs.addRecord(raw, 0, raw.length);
      }
    }
    finally {
      if (re != null) re.destroy();
      if (rs != null) rs.closeRecordStore();
    }
  }
}
```

`RecordMIDlet` saves the updated values back to the `RecordStore` in its `destroyApp()` method. It saves the user name and password from the user interface in the `Preferences` object, then calls the `save()` method to write the new values out to the `RecordStore`. The `save()` method removes all records from the record store, and then adds each key and value pair.

To test out the MIDlet, enter some text into the user name and password fields. Then exit the MIDlet and restart it. You will see the same values loaded into the text fields.

Note that `Preferences` only deals with `String` values, but records can contain any data packed into a byte array. By using stream classes from the `java.io` package, it's possible to store complex data types in records. For example, you could use a `DataOutputStream` wrapped around a `ByteArrayOutputStream` to generate data to be written into the record store. To extract data values, you would use a `DataInputStream` wrapped around a `ByteArrayInputStream` based on the record data.

Listening for Record Changes

`RecordStores` support a JavaBeans-style listener mechanism. Interested objects can listen for changes to a record store by registering themselves as listeners.

The listener interface is `javax.microedition.rms.RecordListener`. You can manage a `RecordStore`'s listeners with the following two methods:

```
public void addRecordListener(RecordListener listener)
public void removeRecordListener(RecordListener listener)
```

The `RecordListener` interface has three methods: `recordAdded()`, `recordChanged()`, and `recordDeleted()`. These are called whenever a record is added, changed, or deleted. Each method is passed the `RecordStore` involved and the ID of the record in question.

Performing RecordStore Queries

The real power of a database is being able to pull out just the record or records you want. In a larger database, this is called *performing a query*. In the `RecordStore` world, you use the `enumerateRecords()` method:

```
public RecordEnumeration enumerateRecords(RecordFilter filter,
    RecordComparator comparator, boolean keepUpdated)
    throws RecordStoreNotOpenException
```

This single method in `RecordStore` involves three different interfaces that you've never seen before. Let's start with the big picture first, and then drill down into the new interfaces.

The `enumerateRecords()` method returns a sorted subset of the records in a `RecordStore`. The `RecordFilter` determines which records will be included in the subset, while the `RecordComparator` is used to sort them. The returned `RecordEnumeration` allows you to navigate through the returned records.

RecordFilter

The simplest interface is `RecordFilter`. When you call `enumerateRecords()` on a `RecordStore`, each record's data is retrieved. `RecordFilter` has a single method, `matches()`, which is called for each record. A record filter should examine the record data and return `true` if the record should be included in the results returned from `enumerateRecords()`.

Here's a simple `RecordFilter` implementation that will only select records whose first byte of data is 7:

```
public class SevenFilter
    implements javax.microedition.rms.RecordFilter {
  public boolean matches(byte[] candidate) {
    if (candidate.length == 0) return false;
    return (candidate[0] == 7);
  }
}
```

RecordComparator

The job of a `RecordComparator` implementation is to determine the order of two sets of record data. `RecordComparator` is similar to the `java.util.Comparator` interface in J2SE.

To implement the `RecordComparator` interface, you just need to define one method:

```
public int compare(byte[] rec1, byte[] rec2)
```

This method examines the data contained in `rec1` and `rec2` and determines which of them should come first in a sorted list. It should return one of the following constants defined in `RecordComparator`:

- `PRECEDES` indicates that `rec1` should come before `rec2`.
- `FOLLOWS` indicates that `rec1` should come after `rec2`.
- `EQUIVALENT` signals that `rec1` and `rec2` are the same, at least as far as sorting is concerned.

The following simple implementation compares each byte of the given records and sorts them numerically. If the two records have the same data, up to the length of the shorter one, then they are deemed EQUIVALENT.

```
public class SimpleComparator
    implements javax.microedition.rms.RecordComparator {
  public int compare(byte[] rec1, byte[] rec2) {
    int limit = Math.min(rec1.length, rec2.length);

    for (int index = 0; index < limit; index++) {
      if (rec1[index] < rec2[index])
        return PRECEDES;
      else if (rec1[index] > rec2[index])
        return FOLLOWS;
    }
    return EQUIVALENT;
  }
}
```

Working with RecordEnumeration

RecordStore's enumerateRecords() method returns an implementation of the RecordEnumeration interface. RecordEnumeration is surprisingly complicated. Its basic function is to allow you to iterate through the records retrieved from the RecordStore. Unlike a regular J2SE Enumeration or Iterator, however, RecordEnumeration allows you to scroll both forward and backward through its contents. In addition, you can peek at the next or previous record ID. Finally, RecordEnumeration offers the possibility of keeping its data synchronized with the actual RecordStore. Behind the scenes, this can be accomplished by registering the RecordEnumeration as a listener for RecordStore changes.

The basic operation of RecordEnumeration is to iterate through a set of records. You can find out if there's a next record by calling hasNextElement(). If the next record exists, you can retrieve its data by calling the following method:

```
public byte[] nextRecord()
    throws InvalidRecordIDException,
           RecordStoreNotOpenException,
           RecordStoreException
```

Alternately, you can retrieve the next record's ID by calling this method:

```
public int nextRecordId() throws InvalidRecordIDException
```

You can't really have your cake and eat it, though; both nextRecord() and nextRecordId() advance the RecordEnumeration to the next record. If you want to retrieve both the ID and the data for the next record, you'd need to call nextRecordId() and then retrieve the record data directly from the RecordStore.

A typical use of RecordEnumeration would be to walk straight through the selected records, like this:

```
// Open a RecordStore rs
// Create a RecordFilter rf
// Create a RecordComparator rc

RecordEnumeration re = rs.enumerateRecords(rf, rc, false);
while (re.hasNextElement()) {
  byte[] recordBytes = re.nextRecord();
  // Process the retrieved bytes.
}
```

The `RecordFilter` and `RecordComparator` can both be `null`, in which case the `RecordEnumeration` will iterate through every record in the record store. The `Preferences` class uses `RecordEnumeration` in this way.

■ **Note** `RecordEnumeration` makes no guarantees about the order of the returned records if the `RecordComparator` is `null`.

As you're moving through the selected records, you can also move backward. `RecordEnumeration` includes `hasPreviousElement()`, `previousRecord()`, and `previousRecordId()` methods that work just like their `next` counterparts.

Four out of the five ways to move the current position in the `RecordEnumeration` are the `nextRecord()`, `nextRecordId()`, `previousRecord()`, and `previousRecordId()` methods. The fifth method is kind of like a rewind button: `reset()` moves the record pointer back to the very beginning of the selected records.

When you're finished using a `RecordEnumeration`, you should release its resources. You can do this by calling `destroy()`, after which the `RecordEnumeration` is no longer usable.

Keeping a RecordEnumeration Up-to-Date

In a multithreaded environment, it's entirely possible that a `RecordStore` will change at the same time you're iterating through a `RecordEnumeration` for the same `RecordStore`. There are two ways to deal with this.

The first thing you can do is call `rebuild()`, which explicitly rebuilds the `RecordEnumeration` based on the `RecordFilter` and `RecordComparator` you originally specified.

The other possibility is to request a `RecordEnumeration` that is automatically updated with any changes to the underlying `RecordStore`. You can do this by passing `true` for the `keepUpdated` parameter of `RecordStore`'s `enumerateRecords()` method. You can find out if the `RecordEnumeration` is automatically updated by calling `isKeptUpdated()`. Furthermore, you can change its state by calling `keepUpdated()`.

Automatically updated `RecordEnumerations` typically register themselves as `RecordListeners` with the underlying `RecordStore`. Each time the `RecordStore` is changed, the `RecordEnumeration` is rebuilt. Keep in mind that this is an expensive operation (in terms of time), so if there are many `RecordStore` changes, you'll be paying a price for it.

Using Resource Files

Resource files are another form of persistent storage. Accessing resource files is very simple, but they are important nevertheless. Resource files can be images, text, or other types of files that are stored in a MIDlet suite JAR. These files are read-only.

You can access a resource file as an `InputStream` by using the `getResourceAsStream()` method in `Class`. A typical usage looks like this:

```
InputStream in = this.getClass().getResourceAsStream("/Robotag-t.png");
```

Summary

The MIDP API for persistent storage is deliberately abstract in recognition that small devices will likely have many different methods for storing data. In MIDP, the central concept for persistent storage is the record store, which is a collection of bits of data called records. A record store is really a tiny database, but the details of exactly how records are stored is specific to a device implementation. The `javax.microedition.rms.RecordStore` class encapsulates all access to persistent storage. It provides methods for accessing and manipulating `RecordStore`s, as well as methods for working with individual records. For more advanced `RecordStore` work, methods and interfaces exist to help keep track of changes to a `RecordStore` or to perform `RecordStore` queries.

CHAPTER 9

Persistent Storage II: File Connection and PIM API

Beyond the typically small persistent storage managed by MIDP's record store mechanism, devices may have additional persistent data storage mechanisms that can be made available to J2ME applications.

JSR 75 addresses two such mechanisms: file systems and Personal Information Management (PIM) databases.

Large file systems can be found on devices that accept plug-in flash memory cards. The File Connection Optional Package provides an API to access these file systems.

PIM databases, such as phone directories and to-do lists, are managed by some devices natively. The PIM Optional Package provides an API for J2ME applications to access these PIM databases.

File Connection Optional Package

Modern devices may have slots for optional flash memory cards (maybe even small hard disks) that can be added. Common flash memory card formats include Secure Data (SD) cards, Compact Flash, and Memory Stick. These memory cards can expand the available persistent storage to megabytes or even gigabytes of data. The record store mechanism of MIDP is inefficient for handling such large-capacity storage. The persistent storage on these cards is accessed as a file system, instead of a database, with directories and files.

A device may expose its file systems through the File Connection Optional Package. This optional API is contained in the `javax.microedition.io.file` package. Much like with a desktop PC, you can read or write files, and you can create or remove directories on the exposed file system. The file systems exposed by this API are usually fairly large in size, from megabytes to gigabytes large.

This optional package is implemented on top of CLDC. The API requires only CLDC 1.0, and works also with CLDC 1.1. The relationship between the File Connection Optional Package and CLDC is illustrated in Figure 9-1.

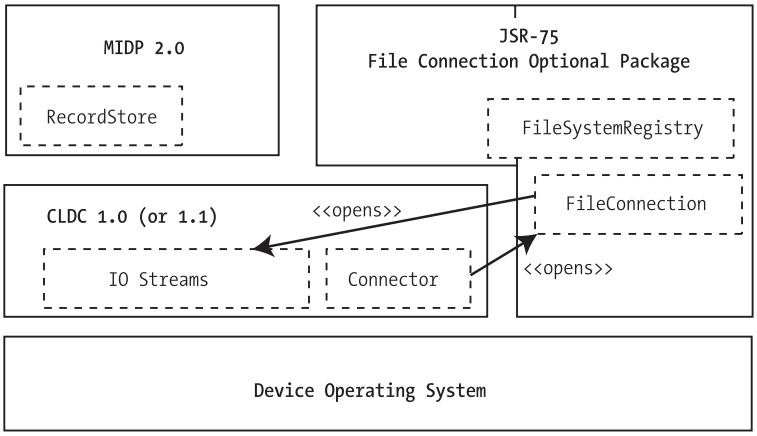


Figure 9-1. *Relationship between File Connection Optional Package and CLDC*

In Figure 9-1, note that the key interface in the API is the `FileConnection` interface. You need to use the `Connector` class from CLDC's Generic Connection Framework (GCF—a primary networking/communications framework covered in Chapter 10) to obtain an instance of a `FileConnection`. Once you have the `FileConnection`, you can start working with the file system, perhaps using the IO stream classes of CLDC to read and write data.

■ **Note** Incidentally, for some implementations, it may be possible to read from (and even write to) specific files in an exposed file system without using the File Connection Optional Package. In these cases, you use `InputConnection` or `OutputConnection` from CLDC instead. However, you will not have the ability to work with directories and discover file names. Using `FileConnection` gives you full access to all that the underlying file system has to offer.

Determining If FileConnection API Is Available

It is always a good idea to make sure an optional API is available on a device before attempting to use it. If you want to confirm that the `FileConnection` optional API is available on a device, check for the system property called `microedition.io.file.FileConnection.version`. All JSR 75 implementations are required to support this property. You can obtain the available version using this code:

```
String currentVersion =
System.getProperty("microedition.io.file.FileConnection.version" )
```

You can also use the returned version to make sure your code is compatible. At this time, however, only version "1.0" has been defined. Null is returned if the API is not available.

Accessing File Systems

You perform read and write operations through the input and output stream classes from the `java.io` package. These streams are a standard part of the CLDC, as Chapter 4 shows.

To obtain a stream to a file in the file system, however, you first need to have an opened file connection. For this, you will need to use the File Connection optional API.

The main interface of this API is the `FileConnection` interface. You obtain an instance of a `FileConnection` by using a method of the `javax.microedition.io.Connector` class. This class is part of the Generic Connection Framework in CLDC. GCF is used primarily to make connections through a network or a communications port (see Chapter 10).

Obtaining FileConnections from GCF

At this time, the important thing you need to know about GCF is that the following static method of the `Connector` class can return a `FileConnection` instance:

```
 public static Connection open(String URL, int mode) throws IOException,
IllegalArgumentException,
  ConnectionNotFoundException, SecurityException
```

The URL to obtain a file connection will always start with "file:///", indicating that a file is accessed on the local host. The full syntax for the URL is actually "file://<hostname>/", but <hostname> is omitted when local. The mode indicates the type of access you want for the file connection. You can use `Connector.READ`, `Connector.WRITE`, or `Connector.READ_WRITE`. For example, you may get an input stream to an existing `abc.txt` file on an SD card using the following:

```
FileConnection fc = (FileConnection) Connector.open("file:///SDCard/abc.txt",
Connector.READ);
InputStream is = fc.openInputStream();
```

You can then use the `InputStream` for reading the file. The `FileConnection` interface has five methods for obtaining a stream:

```
DataInputStream openDataInputStream()
DataOutputStream openDataOutputStream()
InputStream openInputStream()
OutputStream openOutputStream()
OutputStream openOutputStream(long Offset)
```

The second variation of `openOutputStream()` allows you to specify a byte offset to start writing to the file.

■ **Note** The top-level directory of a file system is called the root. Each file system on a device may correspond to a separate flash memory card or storage subsystem, and will have a different root name. The name of the root is arbitrary and totally device dependent. For example, a vendor may choose to name the root of an inserted SD memory card "SDCard1/", while the device's own internal flash file system may have a root name of "InternalFlash/". You can obtain an enumeration of all the available roots on a device using the `FileSystemRegistry`, described later in this chapter.

File or Directory

An open `FileConnection` can be referring to either a directory or a file. You can determine if the connection is associated with a directory via the following method:

```
public boolean isDirectory()
```

Some file systems, such as Win32, support hidden files. Hidden files do not appear on regular directory listings, and are often used for system files. You can determine whether a file or directory is hidden by calling the following method:

```
public isHidden()
```

On a file system that does not support hidden files, `isHidden()` always returns false. You can also control the hidden attribute of a file on file systems that support it, by using this method:

```
public void setHidden(boolean hiddenFlag)
```

Setting `hiddenFlag` to true will make the file hidden, while a false value will make it visible. This method has no effect on file systems that do not support hidden files nor on file systems where you must rename the file to make files hidden.

Modifying File Attributes

Some file attributes may prevent you from reading or writing to a file. You can determine whether a file can be read by using this method:

```
public boolean canRead()
```

Or find out if a file can be written to using the following:

```
public boolean canWrite()
```

To change the read or write attribute of a file on a file system that supports it, use this:

```
public void setReadable(boolean readable)
 throws IOException

public void setWriteable(boolean readable) throws IOException
```

■ **Note** Most of the input/output methods on the `FileConnection` interface will throw `ConnectionClosedException` if the call is made on a closed connection, `IllegalModeException` if a write is tried on a connection that is opened as read-only, and `SecurityException` if the operation would violate security policy. When a `SecurityException` is thrown, the operation is not actually performed. For methods that accept arguments, `NullPointerException` and `IllegalArgumentException` may also be thrown if an error occurs during argument processing.

Directory and File Size

Your application may need to determine the available space on a file system associated with a `FileConnection` instance. You can call the `availableSize()` method to find out the available size in bytes:

```
public long availableSize()
```

This returns the total available space in the entire file system. On plug-in memory cards, this can be up to gigabytes of data. There is another method to find out the size of the storage area already used up:

```
public long usedSize()
```

By adding up the value returned from `availableSize()` and `usedSize()`, you can figure out the total size of the file system.

If you only want to find out the size of the specific file associated with the current `FileConnection` instance, use the following method:

```
public long fileSize()
```

If the `FileConnection` instance refers to a directory, you can find out the total size of all the files in the directory by calling the following method:

```
public long directorySize()
```

Creating New Files or Directories

To create a new file, you first have to use `Connector.open()` with the new file name and `Connector.WRITE` mode. A `FileConnection` will be returned, but the file does not yet exist. You can confirm its nonexistence by calling

```
boolean exists() throws SecurityException, IllegalModeException,
   ConnectionClosedException
```

To create the file, you call

```
public void create() thows IOException
```

Creating a new directory is similar. Use `Connector.open()` with the new directory name. Then call the `mkdir()` method on the returned `FileConnection`:

```
public void mkdir() throws IOException
```

Note that it is not possible to create a directory using the `create()` call for a file using a URL such as "file:///mydir/". The trailing / will cause the `create()` call to throw an `IOException`. Use only the `mkdir()` call for directory creation.

Renaming and Deleting Files and Directories

To delete a file or directory, you need to first open it with `Connector.WRITE` mode enabled, then call the method:

```
public void delete() throws IOException
```

You should immediately call `close()` on the `FileConnection` after a `delete()`. The `FileConnection` is no longer valid once the underlying file has been deleted.

Similarly, to rename a file or directory, open it with `Connector.WRITE` mode enabled, and then call the `rename()` method of the `FileConnection` instance with the new name:

```
public void rename(String newName) throws IOException
```

Listing Directory Content

When you have a `FileConnection` to a directory, you can obtain an `Enumeration` of its content (files and subdirectory) using this method:

```
Enumeration list() throws IOException
Enumeration list(String filter, boolean includeHidden) throws IOException
```

The returned `Enumeration` contains objects of string type. Each object in the enumeration is the name of a file or directory. If the object is a directory, the name will end with `/`.

The second form of `list()` uses a filter that can contain the * (asterisk) wildcard character. For example, a filter value of "*.png" will select only the PNG graphics files in the directory. The `includeHidden` flag indicates whether the matching should be performed against files with the hidden flag set.

To make directory traversal more efficient, `FileConnection` does not force you to go back to GCF and use `Connector.open()` on every level of a new directory (although you can do so if you want to). Instead, a convenient method allows you to dive down a specific subdirectory (or move up) with the current `FileConnection`:

```
public void setFileConnection(String itemName) throws IOException
```

This will reset the `FileConnection` to the specified subdirectory, parent directory, or file. The `itemName` must be a string that is from a `list()`-returned `Enumeration`.

Path and URL Information

Note that the string from a `list()`-returned `Enumeration` does not contain full path information, or any of the "file:///" URL preamble. If you are only navigating subdirectories, you don't need the full URL. However, if you actually need the full URL, you can call this method to get the complete path and preamble:

```
public String getPath()
```

By appending the string from the `list()`-returned `Enumeration` to the string returned from the preceding method, you end up with a full URL. The full URL is useful if you ever need to open the file or directory again using the GCF `Connector.open()`.

If you already have a `FileConnection` open, you can always get the complete URL associated it by calling the following method:

```
public String getURL()
```

To get just the name of the file or directory, without the path and URL preamble, you can call

```
public String getName()
```

Similar to the strings from the `list()` enumeration, a directory name will have a trailing `/` character.

If you are constructing file paths manually, you should always obtain the file separator to use through the system property called `file.separator`. All `FileConnection` implementations must support this property. Use code like this:

```
String fileSep = System.getProperty("file.separator" )
```

Listening for Card Insertion and Removal

A user may insert or remove flash memory card at any time, which will affect the availability of file systems on a device. The File Connection API supports a JavaBeans-style listener mechanism. Interested objects can listen for addition and removal of file system roots (corresponding to insertion and removal of memory cards) by registering themselves as listeners.

The listener interface is `javax.microedition.io.file.FileSystemListener`. Because a device may have multiple file systems (for example, built-in flash memory and a slot for plug-in cards), a central registry class is used to manage the listeners. This central registry is the `javax.microedition.io.file.FileSystemRegistry` class.

You can add and remove file system listeners by using the two static methods of `FileSystemRegistry`:

```
public static boolean addFileSystemListener(FileSystemListener listener) throws
SecurityException,
   NullPointerException
public static boolean removeFileSystemListener(FileSystemListener listener) throws
NullPointerException
```

The returned `boolean` value on these two methods will indicate success of the operation.

The `FileSystemListener` interface has only a single method:

```
void rootChanged(int state, String rootName)
```

This method is called whenever there is a change in the set of file systems available. The state value is either `FileSystemListener.ROOT_ADDED` (for insertion of memory card) or `FileSystemListener.ROOT_REMOVED` (when memory card is removed). The `rootName` will provide the name of the root used to access the file system.

■ **Tip** If you are using the default phone emulator of the J2ME Wireless Toolkit 2.x, the file systems are actually subdirectories under the `appdb\DefaultColorPhone\filesystem` directory. There should be a `root1` default file system (subdirectory) there already. You can also simulate the addition and removal of new file system roots while a MIDlet is running. This can be done by selecting from the emulator's menu MIDlet ➤ External events. A dialog box will appear, allowing you to mount or unmount new file systems.

Discovering the Available File Systems

Another frequent use for the centralized `FileSystemRegistry` is for listing all the available file systems. Recall that each file system has a unique corresponding root name. The `static` method to call to discover all the root names is the following:

```
public static Enumeration listRoots() throws SecurityException
```

The returned value is an `Enumeration` of strings. Each element in the `Enumeration` is an available file system root. Typical code to iterate through the roots may be as follows:

```
Enumeration roots = FileSystemRegistry.listRoots();
String currentRoot = null;
while (roots.hasMoreElements()) {
   currentRoot = (String) roots.nextElement();
   ... do something with the discovered root...
}
```

FileConnection and Security

JSR 75 requires that all implementations of the File Connection Optional Package to isolate the MIDP RMS databases from the file system exposed through `FileConnection`. This means that there will be no way for you to accidentally overwrite any data that is accessed through `RecordStore`.

The specification recommends strongly that general file system access only be granted to designated public areas. It also recommends that file systems be protected based on users, applications, and system. However, enforcement is left up to the individual device implementation. Most CLDC devices are single user, and access restrictions based on user may not make sense.

When you make a call to `Connector.open()`, the MIDP protection domain-based security policy will kick in. For untrusted MIDlet suites, a user must explicitly allow access to the protected `FileConnection` API. This is identical to the behavior when untrusted MIDlet suites access the network through GCR.

For trusted MIDlet suites, a set of permissions is used to provide specific access to the `FileConnection` API. This set of permissions include the following:

```
javax.microedition.io.Connector.file.read
javax.microedition.io.Connector.file.write
```

Review Chapter 3 if you need a refresher on protection domains, permissions, or the MIDP security model in general.

An Example

Putting some of this to work, the example in Listing 9-1 stores preferences to the file system using the File Connection Optional Package. `FileBasedPreferences` is similar to the `RecordStore`-based `Preferences` class from Chapter 8. It maintains a preferences hash table that is persisted to the file system using the File Connection API.

Listing 9-1. *A Preferences Class That Encapsulates File System Access*

```
import java.util.*;
import javax.microedition.io.*;
import javax.microedition.io.file.*;
import java.io.*;

public class FileBasedPreferences implements Runnable {
  private String mDirectoryName;
  private static final String fileURLRoot = "file:///";
  private static final String fileExt = ".pfs";
  private Hashtable mHashtable;
  private boolean mSaving = false;
  private String mFileRoot = null;

  public FileBasedPreferences(String dirName)
  throws IOException {
    mDirectoryName = dirName;
    mHashtable = new Hashtable();
    Enumeration em = FileSystemRegistry.listRoots();
    // Take the first root available for simplicity.
    if (em.hasMoreElements())
      mFileRoot = fileURLRoot + em.nextElement();
    if (mFileRoot != null)
      load();
    else
      throw new IOException("No file system available");
  }

  public String get(String key) {
    return (String)mHashtable.get(key);
  }

  public void put(String key, String value) {
    if (value == null) value = "";
    mHashtable.put(key, value);
  }

  private void load() throws IOException {
    FileConnection fc = null;
    DataInputStream dis = null;
```

```
    StringBuffer fileURL = new StringBuffer(mFileRoot);
    fileURL.append(mDirectoryName);
    fileURL.append(fileExt);
    try {
      fc = (FileConnection) Connector.open(
      fileURL.toString(), Connector.READ);
      if (fc == null)
        return;
      if (!fc.exists()) {
        return;
      }

      dis = fc.openDataInputStream();

      String curInput;
      while ( (curInput = dis.readUTF()) != null ) {
        int index = curInput.indexOf('|');
        String name = curInput.substring(0, index);
        String value = curInput.substring(index + 1);
        put(name, value);
      }
    } catch (Exception ex) {
      // End of file detected the hard way.
    }
    finally {
      if (dis != null) dis.close();
      if (fc != null) fc.close();
    }
  }

  public void save() {
    Thread t = new Thread(this);
    t.start();
  }
  public void run() {
    mSaving = true;
    try {
      savePref();
    } catch (IOException ex) {
    }
    mSaving = false;
  }
  public boolean isSaving() {
    return mSaving;
  }
```

```
  public void savePref() throws IOException {
    FileConnection fc = null;
    DataOutputStream dos = null;
    try {
      // If exists already, first delete file, a little clumsy.
      StringBuffer fileURL = new StringBuffer(mFileRoot);
      fileURL.append(mDirectoryName);
      fileURL.append(fileExt);
      fc = (FileConnection) Connector.open( fileURL.toString(),
Connector.READ_WRITE);
      if (fc.exists()) {
        fc.delete();
        fc.close();
        fc = (FileConnection) Connector.open( fileURL.toString(),
Connector.READ_WRITE);
      }
      fc.create();
      dos = new DataOutputStream(fc.openOutputStream());

      // Now save the preferences records.
      Enumeration keys = mHashtable.keys();
      while (keys.hasMoreElements()) {
        String key = (String)keys.nextElement();
        String value = get(key);
        String pref = key + "|" + value;
        dos.writeUTF(pref);
      }


    }
    finally {
      if (dos != null) {
        dos.flush();
        dos.close();
      }
      if (fc != null) fc.close();

    }
  }
}
```

Note the use of `FileSystemRegistry` to obtain the file system root in the constructor. The first returned file root is used (usually `root1/` for the Wireless Toolkit).

Loading of data is done in the constructor, before the GUI becomes active. However, in the MIDlet, saving of data is performed when handling a `Save` command. Since this is done within the GUI event handling thread, you don't want it to hold it up. The `save()` method starts another thread to perform the actual persistence.

The `run()` method contains the code to write the `HashTable` to the file system. The `mSaving` flag is used to ensure that the user will not exit the application while an I/O thread is still saving data to the file system.

The GUI MIDlet that uses the `FileBasedPreferences` class is called `FCMIDlet`, which is shown in Listing 9-2. The user interface is identical to the one in `RecordMIDlet` from Chapter 8.

Listing 9-2. *Source Code of the FCMIDlet*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;
import javax.microedition.rms.RecordStoreException;
import java.io.*;

public class FCMIDlet
extends MIDlet
implements CommandListener {
  private static final String kUser = "user";
  private static final String kPassword = "password";
  private FileBasedPreferences mPreferences;
  private Form mForm;
  private TextField mUserField, mPasswordField;
  private Command mExitCommand, mSaveCommand;

  public FCMIDlet() {
    try {
      verifyFileConnectionSupport();
      mPreferences = new FileBasedPreferences("preferences");
    }
    catch (IOException ex) {
      mForm = new Form("Exception");
      mForm.append(new StringItem(null, ex.toString()));
      mExitCommand = new Command("Exit", Command.EXIT, 0);
      mForm.addCommand(mExitCommand);
      mForm.setCommandListener(this);
      return;
    }

    mForm = new Form("Login");
    mUserField = new TextField("Name",
    mPreferences.get(kUser), 32, 0);
    mPasswordField = new TextField("Password",
    mPreferences.get(kPassword), 32, 0);
    mForm.append(mUserField);
    mForm.append(mPasswordField);
    mExitCommand =new Command("Exit", Command.EXIT, 0);
    mSaveCommand = new Command("Save", "Save Password", Command.SCREEN, 0);
    mForm.addCommand(mExitCommand);
```

```
    mForm.addCommand(mSaveCommand);
    mForm.setCommandListener(this);
  }

  public void startApp() {
    Display.getDisplay(this).setCurrent(mForm);
  }

  public void pauseApp() {}

  public void savePrefs() {
    // Save the user name and password.
    mPreferences.put(kUser, mUserField.getString());
    mPreferences.put(kPassword, mPasswordField.getString());
    mPreferences.save();
  }
  public void destroyApp(boolean flg) {
  }
  public void commandAction(Command c, Displayable s) {
    if (c == mExitCommand) {
      if (mPreferences == null) {
        destroyApp(true);
        notifyDestroyed();
      }
      else if ( !mPreferences.isSaving()) {
        destroyApp(true);
        notifyDestroyed();
      }
    }
    else if (c == mSaveCommand)
      savePrefs();
  }
  public void verifyFileConnectionSupport() throws IOException {
    String version = "";
    version = System.getProperty("microedition.io.file.FileConnection.version");
    if (version != null) {
      if (!version.equals("1.0"))
        throw new IOException("Package is not version 1.0.");
    }
    else
      throw new IOException("File connection optional package is not available.");
  }
}
```

Note the use of the `verifyFileConnectionSupport()` method to assert the availability of the optional package in the constructor. When the `Exit` command is selected, the MIDlet will terminate only if the `isSaving()` method of the `FileBasedPreferences` instance returns false. Otherwise, the background thread is still saving data to the persistent storage.

You can try out the application. Enter in a user name and a password, and then click the Save button. You can then exit the MIDlet. When you start the MIDlet again, the persisted information should be redisplayed.

■ **Tip** If you are using the default phone emulator of the J2ME Wireless Toolkit 2.x, the file systems are actually subdirectories under the `appdb\DefaultColorPhone\filesystem` directory. You should be able to find the `preferences.pfs` file storing the preference under the `root1` subdirectory.

PIM Optional Package

Many devices, especially phones, have the ability to maintain lists of phone numbers and names. Some devices also store addresses, e-mails, events, to-do lists, and other personal information. This PIM data is stored in PIM databases. Most devices will have built-in applications that manage the PIM data. Until recently, there was no direct way of accessing this information from your MIDP application. A device vendor may now expose access to its PIM databases through the PIM Optional Package, specified in JSR 75.

Figure 9-2 shows the hierarchy of major classes and interfaces in the PIM API.

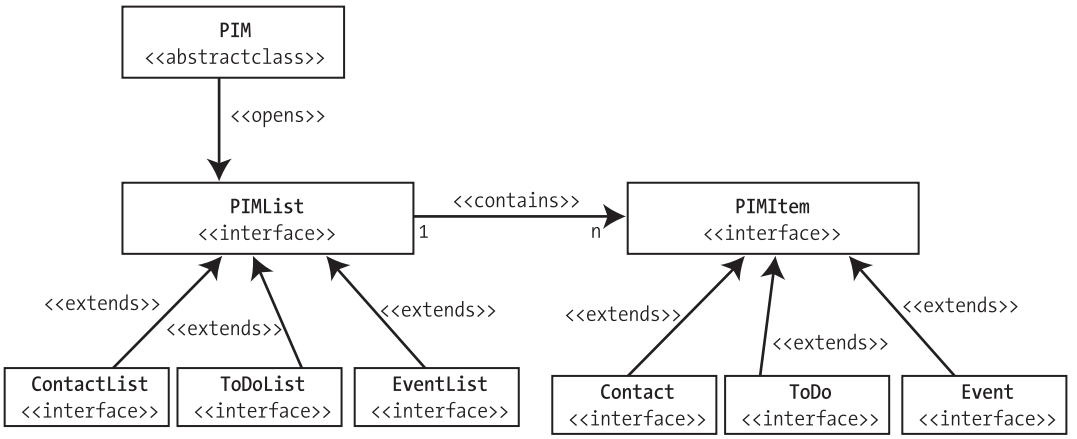


Figure 9-2. *The major classes and interfaces of the JSR 75 PIM API*

In Figure 9-2, PIM is a singleton object that is used to open lists of records. Think of PIM as representing the PIM database. Lists are accessed through the `PIMList` interface. Each list contains items. Each item represents a single record in the PIM database. Items are accessed through the `PIMItem` interface. `Contact`, `Event`, and `ToDo` all inherit from `PIMItem`, while `ContactList`, `EventList`, and `ToDoList` all inherit from `PIMList`.

Determining If PIM Optional Package Is Available

You should check to see if the PIM Optional Package is available on a device before attempting to use it. Check for the system property called `microedition.pim.version`. All PIM Optional Package implementations are required to support it. Use code similar to

```
String currentVersion = System.getProperty("microedition.pim.version " )
```

You should also use the returned version to make sure your code is version compatible. At this time, however, only version "1.0" is available. The call will return null if the optional package is not available.

Obtaining the Singleton PIM Instance

The API centers around the PIM abstract class. You cannot instantiate this class with the `new` operator. However, there is a class factory method to obtain the one and only instance:

```
public static PIM getInstance()
```

Opening the PIM Lists

You can access the PIM lists once you have the singleton instance. A PIM list can be obtained using one of these `openPIMList()` methods:

```
public PIMList openPIMList(int pimListType, int mode) throws PIMException
public PIMList openPIMList(int pimListType, int mode, String name) throws
PIMException
```

The `pimListType` can contain `PIM.CONTACT_LIST`, `PIM.EVENT_LIST`, or `PIM.TODO_LIST`. The JSR 75 specification requires at least one list to be available if the optional package is supported. The access mode can be `PIM.READ_ONLY`, `PIM.READ_WRITE`, or `PIM.WRITE_ONLY`.

JSR 75 allows a device to maintain multiple lists of the same type. Not all implementations will have this need. If you need to, the second form of the `openPIMList()` method enables you to select a list by name and type. The name of the lists available, if an implementation supports multiple lists of the same type, can be obtained via the following:

```
String []  listPIMLists( int  pimListType);
```

`pimListType` is any one of `PIM.CONTACT_LIST`, `PIM.EVENT_LIST`, or `PIM.TODO_LIST`.

Obtaining Items from a PIM List

Once you have a list opened, you can start accessing its content. The `openPIMList()` call returns a `PIMList`. The `javax.microedition.pim.PIMList` interface is the superinterface of `ContactList`, `EventList`, and `ToDoList`. You need to cast it to the expected type before accessing the list, for example:

```
ContactList clist = (ContactList)
     pimInst.openPIMList( PIM.CONTACT_LIST, PIM.READ_WRITE);
```

All the records in a list can be accessed via an `Enumeration` (`java.util.Enmeration`) of `PIMItems`. You can obtain the `Enumeration` using one of the `items()` methods on the `PIMList`:

```
public Enumeration items() throws PIMException
public Enumeration items(PIMItem matchingItem) throws PIMException
public Enumeration items(String matchingValue) throws PIMException
```

The second and third form in the preceding list will both return a subset of the items in a list.

The second form matches based on a supplied `PIMItem` template (which is a contact, an event, or a to-do item). You need to set the fields on this template that you want to match (setting field values is covered later in this chapter; see the section "Modifying Field Values"). For a `String` typed field, you can specify a partial string. For example, specifying "hom" will match both "homing pigeon" and "HOMER".

The third form attempts to perform the partial string match across all string-typed fields of an item. For a `ContactList`, it is essentially saying, "Find me all the contacts that contain the string in any of its (string-typed) fields."

Manipulating Categories

Some PDAs support the notion of a category. You can classify a list of items by categories. A category is a just a string. For example, a "personal" category can be used to flag all the personal contacts in the content list, while a "business" category is used for business contacts. To obtain all the list items in a particular category, you can use the following:

```
public Enumeration itemsByCategory(String category) throws PIMException
```

To get a list of categories supported by the device, call

```
String [] getCategories() throws PIMException
```

If you get a zero-length array in return, you know that either the device does not support categories or the user hasn't defined any.

Once you've determined that the device supports categories, you can add new categories using the following:

```
public void addCategory(String category) throws PIMException
```

This method will never add the same category twice. It will return without throwing an exception if the specified category already exists. To delete a category, use this method:

```
public void deleteCategory(String category, boolean deleteUnassignedItems)
```

Note that some items may end up having no category assigned once a category is deleted. Set the `deleteUnassignedItems` flag to true if you want these items deleted from the list. The `deleteCategory()` method will return without throwing an exception even if the category specified does not exist. It will, however, throw a `PIMException` if categories are not supported on the device.

A category can be renamed using the following method:

```
public void renameCategory(String currentCategoryName, String newCategoryName)
throws PIMException
```

Four methods can be used to manipulate the categories associated with a contact:

```
public String [] getCategories()
public int maxCategories()
public void addToCategory(String category) throws PIMException
public void removeFromCategory(String category)
```

`getCategories()` gets a list of the categories associated with the contact. `maxCategories()` can be used to discover the maximum number of categories that can be assigned to a contact—this is highly implementation dependent. `addToCategory()` will add a category association to a contact. `removeFromCategory()` removes a category association from a contact.

Standard Fields on an Item

A `PIMItem` can hold a contact record, an event record from the event list, or a to-do item from the to-do list. Accordingly, the `PIMItem` interface is the superinterface to the `Contact`, `Event`, and `ToDo` interfaces.

The `PIMItem` interface contains many methods for working with fields within an item. The PIM functions of a device are typically accessed by native applications. This may be a phone directory application on a cell phone or an address book on a wireless PDA. The set of fields supported and their format can be quite different between devices. As a result, the PIM API must be able to deal with a completely flexible set of fields.

Each of the `Contact`, `Event`, and `ToDo` interfaces defines a set of constants that can be used to specify a set of "standard fields" in the record. The standard fields for `Contact` are based on the vCard 3.0 specifications from the Internet Mail Consortium (`http://www.imc.org/pdi/`). The vCard format is a cross-platform data interchange format that is widely used by contact management applications.

■ **Note** The set of standard fields in the `Event` and `ToDo` items is based on the vCalendar 1.0 specification from the Internet Mail Consortium. You can work with these fields in the same way as the fields in `Contact`.

For example, `Contact` defines the standard fields and subfields detailed in Table 9-1. The `Contact` interface has constants defined for all of these fields and subfields.

Table 9-1. *Standard Fields of a Contact Record*

Field Name/Constant	Description	Data Type
`ADDR`	Field specifying address.	`String []`
`ADDR_COUNTRY`	Index into `ADDR` of the country portion of the address.	`String`
`ADDR_EXTRA`	Index into `ADDR` of extra information in the address.	`String`
`ADDR_LOCALITY`	Index into `ADDR` of locality information associated with an address. Typically used to hold city name.	`String`
`ADDR_POBOX`	Index into `ADDR` of the post office box associated with the address.	`String`

Table 9-1. *Standard Fields of a Contact Record (Continued)*

Field Name/Constant	Description	Data Type
ADDR_REGION	Index into ADDR of the region information associated with an address. Typically used to hold province or state name.	String
ADDR_POSTALCODE	Index into ADDR of the postal or zip code portion of an address.	String
BIRTHDAY	Field containing the birthday.	Date
CLASS	Field containing access class information. Can contain Contact.CLASS_CONFIDENTIAL, Contact.CLASS_PRIVATE, or Contact.CLASS_PUBLIC.	int
EMAIL	Field containing the e-mail address.	String
FORMATTED_ADDR	Field containing the complete preformatted address.	String
FORMATTED_NAME	Field containing the preformatted name.	String
NAME	Field containing the name.	String []
NAME_FAMILY	Index.	String
NAME_GIVEN	Index.	String
NAME_OTHER	Index.	String
NAME_PREFIX	Index.	String
NAME_SUFFIX	Index.	String
NICKNAME	Field containing the nickname.	String
NOTE	Field containing additional note.	String
ORG	Field containing the organization name.	String
PHOTO	Field including a photo.	byte []
PHOTO_URL	Field specifying a link to a photo.	String
PUBLIC_KEY	Field containing public encryption key in binary form.	byte []
PUBLIC_KEY_STRING	Field containing public encryption key in string form. May be tied together with PUBLIC_KEY field.	String
REVISION	Field containing date of last modification.	Date
TEL	Field containing a telephone number. No fixed format required.	String
TITLE	Field specifying the job title.	String
UID	Field containing a unique ID.	String
URL	Field containing a link.	String

There are two fields in Contact that are string arrays: NAME and ADDR. These are somewhat special because each member of the string array contains a different subfield. Constants such as NAME_FAMILY contain the corresponding index into the string array. For example, if pimName is the string array containing NAME, then you can access the last name using

```
String lastName = pimName[Contact.NAME_FAMILY];
```

JSR 75 does not require implementation of any of these standard fields. You should check to see whether the field is supported by the actual API implementation before using it. You need to use a method on the `ContactList` (actually `PIMList`, `ContactList`'s superinterface) to check for field support:

```
public boolean isSupportedField(int field)
```

You can also get a list of all the supported fields using this method:

```
public int [] getSupportedFields()
```

Reading Field Values

To read the value in a field, you need to know its data type. Table 9-1 describes the data type of all standard `Contact` fields. You can look up the data type for `Event` and `ToDo` from the JSR 75 Javadocs.

There are accessor methods for each data type on the `Contact` (actually `PIMItem`) interface:

```
public byte [] getBinary(int field, int index)
public long getDate(int field, int index)
public int getInt(int field, int index)
public String getString(int field, int index)
public Boolean getBoolean(int field, int index)
public String [] getStringArray(int field, int index)
```

Each field instance can actually contain multiple values of the same type, which is why an index is needed for the preceding methods. For example, the `Contact.TEL` field may have three values—one for fax, one for work, and one for home. In this case, the three values are accessed on a different index of the `Contact.TEL` field and will each have a different attribute. Attributes are discussed in the next section.

In many cases, there is only one single field value, and using index 0 is adequate. For example, you can get the `Contact.EMAIL` field from a `Contact` instance (called `myContact`) using the following code:

```
String tmpEmail = null;
if ( myContList.isSupportedField(Contact.EMAIL))
  tmpEmail = myContact.getString(Contact.EMAIL, 0);
```

The `Contact.NAME` and `Contact.ADDR` fields are of string array types. The code to access a subfield requires one more level of indexing. For example, to obtain the value of the last name of a `Contact`, use the following:

```
String [] curName = myContact.getStringArrary(Contact.NAME, 0);
String lastName = curName[Contacat.NAME_FAMILY];
```

Adding Attributes to Field Values

Attributes are bit flags used to qualify field values. Attributes defined in the `Contact` interface include `ATTR_FAX`, `ATTR_HOME`, `ATTR_MOBILE`, `ATTR_OTHER`, `ATTR_PAGER`, `ATTR_SMS`, `ATTR_WORK`, `ATTR_AUTO`, `ATTR_ASST`, and `ATTR_PREFERRED`. Attributes may be combined using the | (bitwise or) operator.

Attributes are useful for some fields that can have multiple values. For example, the `Contact.TEL` field may have a value of "402-323-1111" with `ATTR_FAX`, another value of "402-341-8888" with `ATTR_WORK`, and a value of "402-872-2001" with `ATTR_HOME | ATTR_PREFERED`.

Only one value can be marked with `ATTR_PREFERRED`. The index corresponding to the preferred attribute, if set, can be obtained using this method on the `Contact` interface:

```
public int getPreferredIndex(int field)
```

Attributes are specified when adding values to a field. A series of data type–dependent methods on `Contact` (actually `PIMItem`) are available for this purpose:

```
public void addBinary(int field, int attributes, byte[] value,
        int offset, int length)
public void addDate(int field, int attributes, long value)
public void addInt(int field, int attributes, int value)
public void addString(int field, int attributes, String value)
public void addBoolean(int field, int attributes, boolean value)
public void addStringArray(int field, int attributes, String [] value)
```

Most fields are single valued, and not all fields have attributes. You can use `Contact.ATTR_NONE` for an attribute when adding a value to a field.

Creating a New Contact

Creating a new `Contact` is a three-step process (for `Event` or `ToDo`, the procedure is similar):

1. Call the factory method, `createContact()`, on the `ContactList`, returning a new `Contact` for the list.
2. Use the `add<data type>()` methods of the `Contact` to set values for the fields of the `Contact`.
3. Call the `commit()` method on the `Contact` to save the new field values to persistent storage.

The `createContact()` method on the `ContactList` will create a new `Contact` item for the list, with no value set for any of the fields:

```
public Contact createContact()
```

The `commit()` method of `Contact` causes the underlying implementation to save all the new field values to persistent storage.

```
public void commit() throws PIMException
```

For example, the code to create a new `Contact` with only a `Contact.NAME` field may be as follows:

```
ContactList contList = (ContactList)
     PIM.getInstance().openPIMList(PIM.CONTACT_LIST, PIM.READ_WRITE);
Contact ct = list.createContact();
 String [] name = new String[contList.stringArraySize(Contact.NAME)];
 name[Contact.NAME_GIVEN] = "Joe";
 name[Contact.NAME_FAMILY] = "Tanner";
 ct.addStringArray(Contact.NAME,Contact.ATTR_NONE , name);
 ct.commit();
```

Note the use of the `stringArraySize()` method in the preceding code; this method is part of the `ContactList` interface that can be used to obtain the (fixed) array size of string array typed field. The method has the following signature:

```
public int stringArraySize(int stringArrayField)
```

Modifying Field Values

To change the value of the fields in an existing item, you can use any of the type-specific methods on a `Contact`:

```
public void setBinary(int field, int index, int attributes, byte[] value,
 int offset, int length)
public void setDate(int field, int index, int attributes, long value)
public void setInt(int field, int index, int attributes, int value)
public void setString(int field, int index, int attributes, String value)
public void setBoolean(int field, int index, int attributes, boolean value)
public void setStringArray(int field, int index, int attributes, String [] value)
```

Note that every method in the preceding list requires an index to specify the field value to set in the case of fields with multiple values. Most fields are single valued, and using 0 as an index will suffice.

You can determine if any fields in an item has been modified by calling

```
public boolean isModified()
```

Any change you make to the field values in the contact will be persisted to persistent storage when you call the `commit()` method.

Removing Contacts

To remove a `Contact`, you will need to get a reference to the `Contact` to be removed. This can be done by iterating through the `Enumeration` returned from an `items()` method call (see the earlier section "Obtaining Items from a PIM List"). Once you have a reference to the `Contact` to be removed, call the `removeContact()` method on the `ContactList` interface:

```
public void removeContact(Contact contact) throws PIMException
```

There is no method to remove all items from a list. You will need to iterate through the `Enumeration` and remove each one individually.

Working with the PIM API

Putting the API to use, the first MIDlet will write contact information to the PIM database. `SeedMIDlet`, shown in Listing 9-3, writes four contact records into the PIM database using the PIM optional APIs.

Listing 9-3. *Source Code for a MIDlet to Seed the PIM Database with Contacts*

```
import java.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
import javax.microedition.pim.*;

public class SeedMIDlet
extends MIDlet implements CommandListener {
  private Form mForm;
  private Command mExitCommand;

  public SeedMIDlet() {
    try {
      verifyPIMSupport();
      seed();
    }
    catch (Exception ex) {
      mForm = new Form("Exception");
      mForm.append(new StringItem(null, ex.toString()));
      mExitCommand = new Command("Exit", Command.EXIT, 0);
      mForm.addCommand(mExitCommand);
      mForm.setCommandListener(this);
      return;
    }

    mForm = new Form("Data Seeded");
    mForm.append(new StringItem(null, "PIM data stored."));
    mExitCommand = new Command("Exit", Command.EXIT, 0);
    mForm.addCommand(mExitCommand);
    mForm.setCommandListener(this);
  }

  public void startApp() {
    Display.getDisplay(this).setCurrent(mForm);
  }

  public void pauseApp() {}
```

```
public void destroyApp(boolean flg) {
}
public void commandAction(Command c, Displayable s) {
  if (c == mExitCommand) {
    destroyApp(true);
    notifyDestroyed();
  }
}

public void verifyPIMSupport() throws IOException {
  String version = "";
  version = System.getProperty("microedition.pim.version");
  if (version != null) {
    if (!version.equals("1.0"))
      throw new IOException("Package is not version 1.0.");
  }
  else
    throw new IOException("PIM optional package is not available.");
}

private ContactList contList = null;
private void seed() throws PIMException {
  try {
    PIM pimInst = PIM.getInstance();
    contList = (ContactList)
    pimInst.openPIMList(PIM.CONTACT_LIST, PIM.READ_WRITE);
  }
  catch (PIMException ex) {
    // Contact list is not supported.
  }
  addContact(contList, "Jack", "Goldburg", "2345 High Park Ave",
  "Orlando", "USA", "32817");
  addContact(contList, "Mary", "Johnson", "777 Lucky Road",
  "London", "UK", "SW10 OXE");
  addContact(contList, "Johnathan", "Knudsen", "234 Sunny Java Street",
  "Sausalito", "USA", "94965");
  addContact(contList, "Sing", "Li", "168 Technology Drive",
  "Edmonton", "Canada", "T6G 2E1");
  if (contList != null)
    contList.close();
  contList = null;

}
```

```
  private void addContact( ContactList list, String firstName, String lastName,
  String street, String city, String country, String postalcode)
  throws PIMException {
    Contact ct = list.createContact();
    String [] name = new String[contList.stringArraySize(Contact.NAME)];
    name[Contact.NAME_GIVEN] = firstName;
    name[Contact.NAME_FAMILY] = lastName;
    ct.addStringArray(Contact.NAME,Contact.ATTR_NONE , name);
    String [] addr = new String[contList.stringArraySize(Contact.ADDR)];
    addr[Contact.ADDR_STREET] = street;
    addr[Contact.ADDR_LOCALITY] = city;
    addr[Contact.ADDR_COUNTRY] = country;
    addr[Contact.ADDR_POSTALCODE] = street;
    ct.addStringArray(Contact.ADDR, Contact.ATTR_NONE , addr);
    ct.commit();
  }
}
```

Note the use of the `verifyPIMSupport()` method to check for PIM Optional Package before proceeding. The `addContact()` method is used to add a contact to the PIM list. Only the `NAME` and `ADDR` fields are set in this example.

Build and run this on the emulator before proceeding with the next MIDlet. This will seed the PIM database with the contact records.

The PIM MIDlet in Listing 9-4 reads the contact list using the PIM optional API and shows the names of all the contacts in the database.

Listing 9-4. *A MIDlet to Display Contact Names in the PIM Database*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;
import javax.microedition.pim.*;
import java.io.*;
import java.util.*;
import javax.microedition.lcdui.List;

public class PIMMIDlet
extends MIDlet
implements CommandListener {
  private ContactList contList = null;
  private Enumeration contacts = null;
```

```
private Form mForm;
private List mNameList;
private Command mExitCommand;
public PIMMIDlet() {
  try {
    verifyPIMSupport();
    PIM pimInst = PIM.getInstance();
    contList = (ContactList)
    pimInst.openPIMList(PIM.CONTACT_LIST, PIM.READ_ONLY);
    contacts = contList.items();
  }
  catch (Exception ex) {
    mForm = new Form("Exception");
    mForm.append(new StringItem(null, ex.toString()));
    mExitCommand = new Command("Exit", Command.EXIT, 0);
    mForm.addCommand(mExitCommand);
    mForm.setCommandListener(this);
    return;
  }

  if (contacts == null)
    return;
  mNameList = new List("List of contacts", List.EXCLUSIVE);
  while (contacts.hasMoreElements()) {
    Contact tCont = (Contact) contacts.nextElement();
    int [] flds = tCont.getFields();
    String [] nameValues = tCont.getStringArray( Contact.NAME, 0);
    String firstName = nameValues[Contact.NAME_GIVEN];
    String lastName = nameValues[Contact.NAME_FAMILY];
    mNameList.append(lastName + ", " + firstName, null);
  }


  mExitCommand =new Command("Exit", Command.EXIT, 0);
  mNameList.addCommand(mExitCommand);
  mNameList.setCommandListener(this);
}

public void startApp() {
  Display.getDisplay(this).setCurrent(mNameList);
}
```

```
  public void pauseApp() {}
  public void destroyApp(boolean flg) {
  }
  public void commandAction(Command c, Displayable s) {
    if (c == mExitCommand) {
      destroyApp(true);
      notifyDestroyed();
    }
  }
  public void verifyPIMSupport() throws IOException {
    String version = null;
    version = System.getProperty("microedition.pim.version");
    if (version != null) {
      if (!version.equals("1.0"))
        throw new IOException("Package is not version 1.0.");
    }
    else
      throw new IOException("PIM optional package is not available.");
  }
}
```

In the constructor, notice the use of the `items()` method of the `ContactList` to obtain an `Enumeration` of contacts. The `Contact.NAME_GIVEN` and `Contact.NAME_FAMILY` subfields of the `Contact.NAME` field are then extracted and displayed in a GUI list.

Summary

JSR 75 specifies two optional packages for persistent storage beyond the record store mechanism of MIDP.

The File Connection Optional Package exposes an API that can be used by applications to access a device's file systems. These file systems typically correspond to a flash memory card that can be added or removed at any time. A centralized file system registry that tracks the addition and removal of file systems is available to applications using the `FileConnection` API.

The PIM Optional Package enables applications to access PIM databases. These databases are typically created and maintained by native PIM applications. You can add, modify, or delete records contained in contacts, events, and to-do lists. PIM applications across different devices may maintain different data fields. The API handles these differences by mapping to a standard set of fields, selected from the vCard and vCalendar personal data interchange specifications from the Internet Email Consortium.

CHAPTER 10

Connecting to the World

It's cool running Java on mobile phones and pagers, but the real kicker is getting your MIDlets connected to the Internet. With an Internet connection, you can write applications that allow you to access information and do work from your mobile telephone, from wherever you are in the world.

The Generic Connection Framework

The CLDC defines an extremely flexible API for network connections, the *generic connection framework*. The core GCF is contained in the `javax.microedition.io` package and based around the `Connection` interface. Figure 10-1 details the `Connection` interface and its various child interfaces.

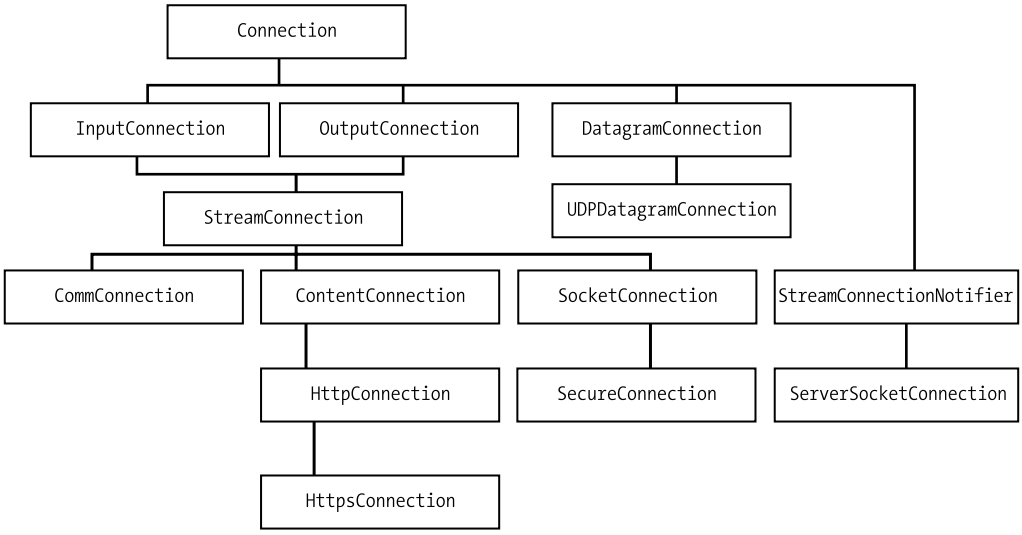


Figure 10-1. *The Connection family tree*

The link between the Connection interfaces and reality is a class called javax.microedition.io.Connector. The basic idea is that you pass a connection string to one of Connector's static methods and get back some Connection implementation. A *connection string* looks something like a URL, but there are various other possibilities. The connection string socket://apress.com:79 might open a TCP/IP connection to apress.com on port 79, then return a StreamConnection implementation. Chapter 9 used a FileConnnection from the JSR 75 optional package to access file systems.

MIDP 2.0 requires support of Hypertext Transfer Protocol (HTTP) connections. You pass an HTTP URL to Connector and get back an implementation of HttpConnection. Mandatory support for HTTPS connections (secure HTTP) is also required by MIDP 2.0. There are also standardized connection strings for several types of connections. We'll discuss these later in this chapter (see the sections following "Making a Connection with HTTP GET").

HttpConnection's methods are detailed in Figure 10-2. Most of the methods in HttpConnection have to do with details of HTTP, which we won't cover here. We'll cover everything you need to know to connect to a server here, including both GET and POST requests. If you need to dig deeper, you can read RFC 2616 (one of the Internet standards documents), available at http://ietf.org/rfc2616.html. Note that MIDP uses a subset of the full HTTP 1.1; only the GET, POST, and HEAD commands are required.

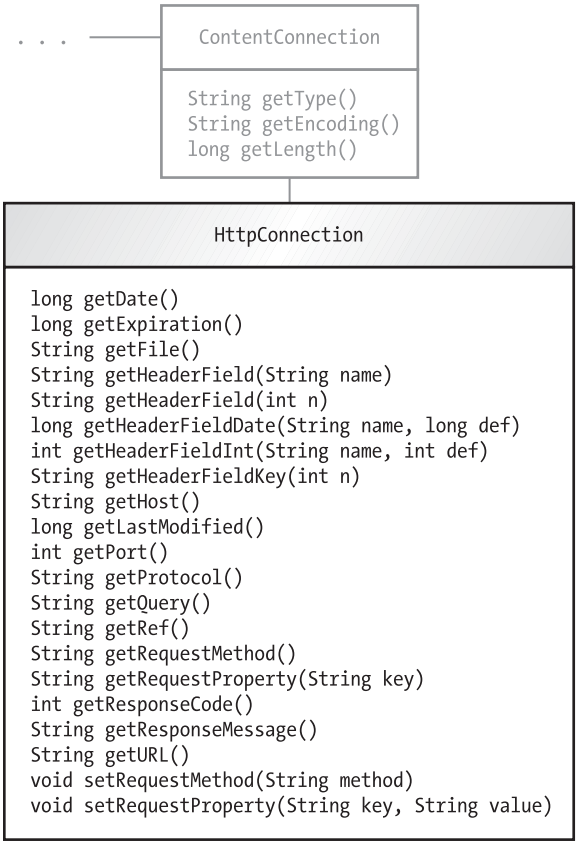


Figure 10-2. *The HttpConnection interface*

Review of HTTP

This section presents a brief review of the Hypertext Transfer Protocol. The whole story is in RFC 2616; this section covers the essentials.

Requests and Responses

HTTP is built around requests and responses. A client sends a request to a server—something like, "Please give me such-and-such HTML page." The server sends back a response—something like, "Here's the file," or, "I don't know what you're talking about."

Requests and responses have two parts: headers and content. If you type a URL into your browser, the browser creates an HTTP request (mostly headers) and sends it to a server. The server finds the requested file and sends it back in an HTTP response. The response headers describe things like the type of web server, the file type of the response, the length of the response, and other information. The response content is the data of the file itself.

Parameters

Browsers and other HTTP clients request specific named resources from HTTP servers. In addition, clients can pass parameters to the server. Parameters are simple name and value pairs. For example, a client might send a `userid` parameter with a value of "jonathan" to a server. HTTP also supports passing binary data to the server in the body of a request, and the Java stream classes make it easy to exchange a variety of data types.

When a browser is the HTTP client, parameters are generally collected from HTML forms. You've seen these forms, like the one in which you fill in your shipping address and your credit card number. Form values are sent as parameters to a web server when you click the `Submit` or `Next` button on the form.

The client encodes parameters before they are sent to the server. Parameters are passed as name and value pairs; multiple parameters are separated by ampersands. The exact way that parameters are encoded is documented in the J2SE documentation for `java.net.URLEncoder`. The rules are relatively simple.

1. The space character is converted to a plus (+) sign.
2. The following characters remain unchanged: lowercase letters a through z, uppercase letters A through Z, the numbers 0 through 9, the period (.), the hyphen (-), the asterisk (*), and the underscore (_).
3. All other characters are converted into "%xy", where "xy" is a hexadecimal number that represents the low 8 bits of the character.

GET, HEAD, and POST

The simplest HTTP operation is GET. This is what happens when you type a URL into your browser. The browser says, "GET me this URL," and the server responds with the headers and content of the response.

With a GET request, parameters are added to the end of the URL in encoded form. (Some servers have trouble with very long URLs; if you have a lot of parameters, or binary data, you

may wish to pass data in the body of the HTTP request.) For example, suppose the following hypothetical URL maps to a servlet or some other server-side component of your application:

```
http://jonathanknudsen.com/simple
```

Adding a parameter is easy. If you want to pass a parameter with a name of `user` and a value of "jonathan", you would use the following URL:

```
http://jonathanknudsen.com/simple?user=jonathan
```

Additional name and value pairs can be added, separated by ampersands:

```
http://jonathanknudsen.com/simple?user=jonathan&zip=08540&day=saturday
```

The HEAD operation is identical to GET, but the server sends back only the headers of the response.

POST is basically the same as GET, but parameters are handled differently. Instead of being pasted on the end of the URL, as they are with GET, the parameters are passed as the body of the request. They are encoded in the same way.

Making a Connection with HTTP GET

Loading data from a server is startlingly simple, particularly if you're performing an HTTP GET. Simply pass a URL to `Connector`'s static `open()` method. The returned `Connection` will probably be an implementation of `HttpConnection`, but you can just treat it as an `InputConnection`. Then get the corresponding `InputStream` and read data to your heart's content.

In code, it looks something like this:

```
String url = "http://jonathanknudsen.com/simple";
InputConnection ic = (InputConnection)Connector.open(url);
InputStream in = ic.openInputStream();
// Read stuff from the InputStream
ic.close();
```

Most of the methods involved can throw a `java.io.IOException`. We've omitted the `try` and `catch` blocks from the example for clarity.

That's all there is to it. You can now connect your MIDlets to the world. Network access is subject to security policies on the device. We'll talk more about this near the end of this chapter, in the section "Permissions for Network Connections."

Passing Parameters

With HTTP GET, all parameters are passed to the server in the body of the URL. This makes it easy to send parameters to the server. The following code fragment shows how two parameters can be passed:

```
String url = "http://localhost/midp/simple?pOne=one+bit&pTwo=two";
InputConnection ic = (InputConnection)Connector.open(url);
InputStream in = ic.openInputStream();
```

The first parameter is named “pOne” and has “one bit” as a value; the second parameter is named “pTwo” and has “two” as a value.

A Simple Example

HTTP isn’t all about exchanging HTML pages. It’s actually a generic file-exchange protocol. In this section, we’ll look at an example that loads an image from the network and displays it. Listing 10-1 shows the source code for `ImageLoader`, a MIDlet that retrieves an image from the Internet and displays it on the screen.

Listing 10-1. *Retrieving an Image from the Internet*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;

public class ImageLoader
    extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;
  private Form mForm;

  public ImageLoader() {
    mForm = new Form("Connecting...");
    mForm.addCommand(new Command("Exit", Command.EXIT, 0));
    mForm.setCommandListener(this);
  }

  public void startApp() {
    if (mDisplay == null) mDisplay = Display.getDisplay(this);
    mDisplay.setCurrent(mForm);

    // Do network loading in a separate thread.
    Thread t = new Thread(this);
    t.start();
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT)
      notifyDestroyed();
  }
```

```
public void run() {
  HttpConnection hc = null;
  DataInputStream in = null;

  try {
    String url = getAppProperty("ImageLoader-URL");
    hc = (HttpConnection)Connector.open(url);
    int length = (int)hc.getLength();
    byte[] data = null;
    if (length != -1) {
      data = new byte[length];
      in = new DataInputStream(hc.openInputStream());
      in.readFully(data);
    }
    else {
      // If content length is not given, read in chunks.
      int chunkSize = 512;
      int index = 0;
      int readLength = 0;
      in = new DataInputStream(hc.openInputStream());
      data = new byte[chunkSize];
      do {
        if (data.length < index + chunkSize) {
          byte[] newData = new byte[index + chunkSize];
          System.arraycopy(data, 0, newData, 0, data.length);
          data = newData;
        }
        readLength = in.read(data, index, chunkSize);
        index += readLength;
      } while (readLength == chunkSize);
      length = index;
    }
    Image image = Image.createImage(data, 0, length);
    ImageItem imageItem = new ImageItem(null, image, 0, null);
    mForm.append(imageItem);
    mForm.setTitle("Done.");
  }
  catch (IOException ioe) {
    StringItem stringItem = new StringItem(null, ioe.toString());
    mForm.append(stringItem);
    mForm.setTitle("Done.");
  }
```

```
    finally {
      try {
        if (in != null) in.close();
        if (hc != null) hc.close();
      }
      catch (IOException ioe) {}
    }
  }
}
```

The `run()` method contains all of the networking code. It's fairly simple; we pass the URL of an image (retrieved as an application property) to `Connector`'s `open()` method and cast the result to `HttpConnection`. Then we retrieve the length of the image file, using the `getLength()` method. Given the length, we create a byte array and read data into it. Finally, having read the entire image file into a byte array, we can create an `Image` from the raw data.

If the content length is not specified, the image data is read in chunks, the size of which can be implementation dependent.

You'll need to specify the MIDlet property `ImageLoader-URL` in order for this example to work correctly. Note that you need to specify the URL of a PNG image, not of a JPEG or GIF. The URL `http://65.215.221.148:8080/wj2/res/java2d_sm_ad.png` produces the results shown in Figure 10-3.

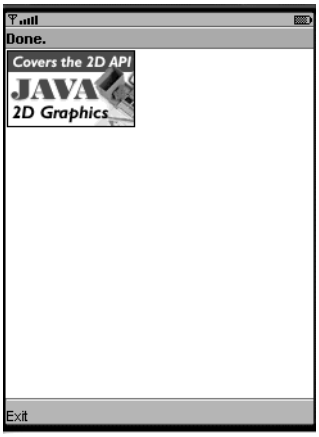


Figure 10-3. *The ImageLoader example*

Posting a Form with HTTP POST

Posting a form is a little more complicated on the MIDlet side. In particular, there are request headers that need to be set in `HttpConnection` before the server is contacted. The process works like this:

1. Obtain an `HttpConnection` from `Connector`'s `open()` method.
2. Modify the header fields of the request. In particular, you need to change the request method by calling `setRequestMethod()`, and you should set the "Content-Length" header by calling `setRequestProperty()`. This is the length of the parameters you will be sending.
3. Obtain the output stream for the `HttpConnection` by calling `openOutputStream()`. This sends the request headers to the server.
4. Send the request parameters on the output stream returned from the `HttpConnection`. Parameters should be encoded as described earlier (and in the documentation for the J2SE class `java.net.URLEncoder`, see `http://java.sun.com/j2se/1.4.2/docs/api/java/net/URLEncoder.html`).
5. Read the response from the server from the input stream retrieved from `HttpConnection`'s `openInputStream()` method.

The following example, Listing 10-2, demonstrates how to send a single parameter to a server using an HTTP POST. Multiple parameters can be assembled by joining them with an ampersand separator. Note that the parameter in this example has been encoded as described previously. In this example, the parameter value "Jonathan Knudsen!" has been encoded to "Jonathan+Knudsen%21". Listing 10-3 shows a very simple servlet that can communicate with `PostMIDlet`.

Listing 10-2. *A Simple MIDlet Performing an HTTP POST*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;

public class PostMIDlet
    extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;
  private Form mForm;

  public PostMIDlet() {
    mForm = new Form("Connecting...");
    mForm.addCommand(new Command("Exit", Command.EXIT, 0));
    mForm.setCommandListener(this);
  }

  public void startApp() {
    if (mDisplay == null) mDisplay = Display.getDisplay(this);
    mDisplay.setCurrent(mForm);
```

```
  // Do network loading in a separate thread.
  Thread t = new Thread(this);
  t.start();
}

public void pauseApp() {}

public void destroyApp(boolean unconditional) {}

public void commandAction(Command c, Displayable s) {
  if (c.getCommandType() == Command.EXIT)
    notifyDestroyed();
}

public void run() {
  HttpConnection hc = null;
  InputStream in = null;
  OutputStream out = null;

  try {
    String message = "name=Jonathan+Knudsen%21";
    String url = getAppProperty("PostMIDlet-URL");
    hc = (HttpConnection)Connector.open(url);
    hc.setRequestMethod(HttpConnection.POST);
    hc.setRequestProperty("Content-Type",
        "application/x-www-form-urlencoded");
    hc.setRequestProperty("Content-Length",
        Integer.toString(message.length()));
    out = hc.openOutputStream();
    out.write(message.getBytes());
    in = hc.openInputStream();
    int length = (int)hc.getLength();
    byte[] data = new byte[length];
    in.read(data);
    String response = new String(data);
    StringItem stringItem = new StringItem(null, response);
    mForm.append(stringItem);
    mForm.setTitle("Done.");
  }
  catch (IOException ioe) {
    StringItem stringItem = new StringItem(null, ioe.toString());
    mForm.append(stringItem);
    mForm.setTitle("Done.");
  }
```

```
    finally {
      try {
        if (out != null) out.close();
        if (in != null) in.close();
        if (hc != null) hc.close();
      }
      catch (IOException ioe) {}
    }
  }
}
```

Listing 10-3. *A Simple Servlet That Responds to PostServlet*

```
import javax.servlet.http.*;
import javax.servlet.*;
import java.io.*;

public class PostServlet extends HttpServlet {
  public void doPost(HttpServletRequest request,
      HttpServletResponse response)
      throws ServletException, IOException {
    String name = request.getParameter("name");

    String message = "Received name: '" + name + "'";
    response.setContentType("text/plain");
    response.setContentLength(message.length());
    PrintWriter out = response.getWriter();
    out.println(message);
  }
}
```

You'll need to specify the MIDlet property `PostMIDlet-URL` in order for this example to work correctly. The URL `http://65.215.221.148:8080/wj2/post` can be used for testing.

Using Cookies for Session Tracking

HTTP is a stateless protocol, which means that each request and response pair is a separate conversation. Sometimes, though, you want the server to remember who you are. This can be done with a *session*. On the server side, a session is just a collection of information. When the client sends an HTTP request to the server, it includes a session ID as part of the request. The server can then look up the corresponding session and have some idea of the identity (or at least the state) of the client.

The most common way to store a session ID on the client side is using HTTP *cookies*. A cookie is just a little piece of data that is passed from the server to the client in an HTTP response. Most web browsers automatically store cookies and will send them back to the appropriate server when a new request is made.

In the MIDP world, of course, there's no web browser taking care of cookies for you. You have to do it yourself. Fortunately, it's not very complicated.

Network code that maintains a server session ID needs to do two things:

1. When receiving a response from a server, check for a cookie. If there is a cookie present, save it away for later (perhaps in a member variable, record store, or file). A cookie is just another HTTP response header line. You can check for a cookie by calling `getHeaderField()` on an `HttpConnection` object after the request has been sent.
2. When sending a request to the server, send the session ID cookie if it has been previously received. Again, sending a cookie to the server is just a matter of putting it in the request headers, using `HttpConnection`'s `setRequestProperty()` method.

Each time you send a request to the server, you will be sending a session ID as a request header. The server uses this session ID to look up a session object that can be used, server side, to do useful stuff like retrieve preferences or maintain a shopping cart.

It's not hard to implement this behavior in a MIDlet. If you have a session ID cookie handy, you should send it when you open up an HTTP connection to the same server, like this:

```
HttpConnection hc = (HttpConnection)Connector.open(url);
if (mSession != null)
    hc.setRequestProperty("cookie", mSession);
```

This code assumes you have a session ID cookie saved away in the `mSession` member variable. The first time you contact the server, of course, you won't have a session ID cookie.

■ **Note** In production code, if you save cookie in persistent storage such as a record store or file, you should check the cookie to see if it has expired before sending it back.

Later, when you receive a response from an HTTP request, look for a cookie. If you find one, parse out the session ID and save it away, like this:

```
InputStream in = hc.openInputStream();

String cookie = hc.getHeaderField("Set-cookie");
if (cookie != null) {
  int semicolon = cookie.indexOf(';');
  mSession = cookie.substring(0, semicolon);
}
```

The cookie string needs to be parsed because it comes in two pieces. The first piece contains the cookie value: the session ID—that's the part we parse out and save. The second part contains a cookie attribute: a path that can be used to determine when the cookie should be sent back to the server.

For more information on the different parts of a cookie string and how they are used, see `http://www.ietf.org/rfc/rfc2965.txt` and `http://www.ietf.org/rfc/rfc2109.txt`.

■ **Note** In some applications, a server may return multiple cookie values. RFC 2965 has provisions for this. In these cases, the cookie string parsing code can be considerably more complex than this example.

Listing 10-4 shows a class, `CookieMIDlet`, that uses this technique to maintain a session with a server. It has a very bland user interface—just an empty `Form` with two commands. If you invoke the `Send` command, the MIDlet sends an HTTP request and receives a response using the cookie handling described earlier.

Listing 10-4. *Saving a Server Session ID Cookie*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

public class CookieMIDlet
    extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;
  private Form mForm;

  private String mSession;

  public void startApp() {
    mDisplay = Display.getDisplay(this);

    if (mForm == null) {
      mForm = new Form("CookieMIDlet");

      mForm.addCommand(new Command("Exit", Command.EXIT, 0));
      mForm.addCommand(new Command("Send", Command.SCREEN, 0));
      mForm.setCommandListener(this);
    }

    mDisplay.setCurrent(mForm);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}
```

```
  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT) notifyDestroyed();
    else {
      Form waitForm = new Form("Connecting...");
      mDisplay.setCurrent(waitForm);
      Thread t = new Thread(this);
      t.start();
    }
  }

  public void run() {
    String url = getAppProperty("CookieMIDlet-URL");

    try {
      // Query the server and retrieve the response.
      HttpConnection hc = (HttpConnection)Connector.open(url);
      if (mSession != null)
        hc.setRequestProperty("cookie", mSession);
      InputStream in = hc.openInputStream();

      String cookie = hc.getHeaderField("Set-cookie");
      if (cookie != null) {
        int semicolon = cookie.indexOf(';');
        mSession = cookie.substring(0, semicolon);
      }

      int length = (int)hc.getLength();
      byte[] raw = new byte[length];
      in.read(raw);

      String s = new String(raw);
      Alert a = new Alert("Response", s, null, null);
      a.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(a, mForm);

      in.close();
      hc.close();
    }
    catch (IOException ioe) {
      Alert a = new Alert("Exception", ioe.toString(), null, null);
      a.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(a, mForm);
    }
  }
}
```

On the server side, things are much simpler, as you'll see in Listing 10-5. If you're writing Java servlets, you don't even have to worry about cookies. Instead, you just deal with an `HttpSession` object. The code that follows shows a servlet that interacts with `CookieMIDlet`; it implements a session-based hit counter. It's been tested on Tomcat 5.5 but should work fine on other servers. Note that you will have to map the URL used by the MIDlet to this servlet class; for details, see an introductory book on servlets or your server's documentation.

Listing 10-5. *A Simple Session Handling Servlet*

```
import javax.servlet.http.*;
import javax.servlet.*;
import java.io.*;
import java.util.*;

public class CookieServlet extends HttpServlet {
  private Map mHitMap = new HashMap();

  public void doGet(HttpServletRequest request,
      HttpServletResponse response)
      throws ServletException, IOException {
    HttpSession session = request.getSession();

    String id = session.getId();

    int hits = -1;

    // Try to retrieve the hits from the map.
    Integer hitsInteger = (Integer)mHitMap.get(id);
    if (hitsInteger != null)
      hits = hitsInteger.intValue();

    // Increment and store.
    hits++;
    mHitMap.put(id, new Integer(hits));

    String message = "Hits for this session: " + hits + ".";

    response.setContentType("text/plain");
    response.setContentLength(message.length());
    PrintWriter out = response.getWriter();
    out.println(message);
  }
}
```

The servlet retrieves the `HttpSession` object. Then it pulls out the session ID and uses it as a key into a map of hit counts. After retrieving and incrementing the hit count for the session, the servlet sends it as the response back to the MIDlet. You can start up multiple copies of the

emulator and run them simultaneously to see how the hit counts are independent of each other and associated with each session.

To test the MIDlet on a server without setting up your own, you can set the MIDlet property `CookieMIDlet-URL` to the URL `http://65.215.221.148:8080/wj2/cookie`.

Design Tips

This section contains some suggestions about creating networked MIDlets.

1. Use GET rather than POST. It's simpler, and you won't have to worry about fiddling around with the request headers.
2. Don't hard-code URLs. Put them in a MIDlet property in the application descriptor. This will make it possible to change the URL without recompiling your code.
3. Put network access in a separate thread. Network access always takes time; it shouldn't hold up the user interface. Furthermore, you must let your users know what's going on. Put up a "loading progress" type of message or some kind of indication that your application is trying to access a network resource.
4. Make sure you handle exceptions gracefully. Network connections on wireless devices are not tremendously reliable, so you should make sure you're prepared for the worst. Catch all your exceptions and do something reasonable.
5. Clean up after yourself. On a small device, resources are scarce, so be sure to close connections when you are done with them. `try - finally` blocks are especially useful for ensuring that unused streams and connections are closed.[1] The code in `Jargoneer` (Chapter 2) demonstrates this technique.

Using HTTPS

HTTP is not a secure protocol. It operates on top of TCP/IP sockets. Information exchanged using HTTP is highly susceptible to eavesdroppers. A more secure alternative, HTTPS, runs atop Transport Layer Security (TLS), Secure Sockets Layer (SSL), or a similar protocol. TLS and SSL provide a layer of authentication and encryption between sockets and higher-level protocols like HTTP, POP3, SMTP, and NNTP.

TLS 1.0 is really just an updated version of SSLv3. For more information on these protocols, see `http://wp.netscape.com/eng/ssl3/` and `http://www.ietf.org/rfc/rfc2246.txt`.

In typical TLS interactions, the server sends a certificate to the client to authenticate itself. The client must have Certificate Authority (CA) root certificates on hand to verify the server's certificate. (The J2ME Wireless Toolkit comes with a utility, `MEKeyTool`, that can be used to modify the set of CA root certificates used by the toolkit emulator. Real devices may have similar utilities, but in general, you'll have to make sure that your server certificate is signed by a CA that is widely recognized.) If the client can verify the certificate, the client will then send a secret value

1. You are probably familiar with the `try - catch` blocks that are used in Java for exception handling. The `finally` clause is not as well known, but it is very useful. Code in the `finally` block will be executed regardless of how control leaves the `try` block.

to the server, encrypted with the server's public key. The server and the client both derive a *session key* from this secret value, which is used to encrypt all subsequent traffic sent between the client and server.

The generic connection framework makes it very easy to obtain HTTPS connections. All you have to do is construct an HTTPS connection string. So instead of this:

```
HttpConnection hc = (HttpConnection)
    Connector.open("http://www.cert.org/");
```

you would do this:

```
HttpsConnection hc = (HttpsConnection)
    Connector.open("https://www.cert.org/");
```

It's really that simple. `HttpsConnection` represents HTTP carried over some secure transport.

`HttpsConnection` is an extension of `HttpConnection`; it adds a `getPort()` method so that you can find out the server's port number. The default port for HTTPS is 443. More importantly, `HttpsConnection` has a `getSecurityInfo()` method that returns information about the secure connection. The new `SecurityInfo` interface encapsulates information about the cipher suite in use, the name and version of the secure protocol, and the server's certificate. The certificate is an implementation of `javax.microedition.pki.Certificate` and includes standard information like the subject, signer, signature algorithm, and validity dates of the certificate.

The following example shows how you can retrieve the subject of a server certificate from an HTTPS connection:

```
String url = "https://www.cert.org/";
HttpsConnection hc = (HttpsConnection)Connector.open(url);
SecurityInfo si = hc.getSecurityInfo();
Certificate c = si.getServerCertificate();
String subject = c.getSubject();
```

Using Datagram Connections

In this section, we'll briefly describe datagram connections. Although support for datagrams is not mandated by the MIDP specification, certain device implementations may choose to support datagram connections. Unlike stream-oriented connections, datagram connections are *connectionless*. This means that you can fire packets of data around the network, but you have no guarantee that they will reach their destination in the right order, or that they will even arrive at all.

Datagram communications is based on two interfaces in the `javax.microedition.io` package, `DatagramConnection` and `Datagram`. Figure 10-4 shows the methods in `DatagramConnection`.

The first step is to use the generic connection framework to obtain a `DatagramConnection`—something like this:

```
String url = "datagram://jonathanknudsen.com:7999";
DatagramConnection dc = (DatagramConnection)Connector.open(url);
```

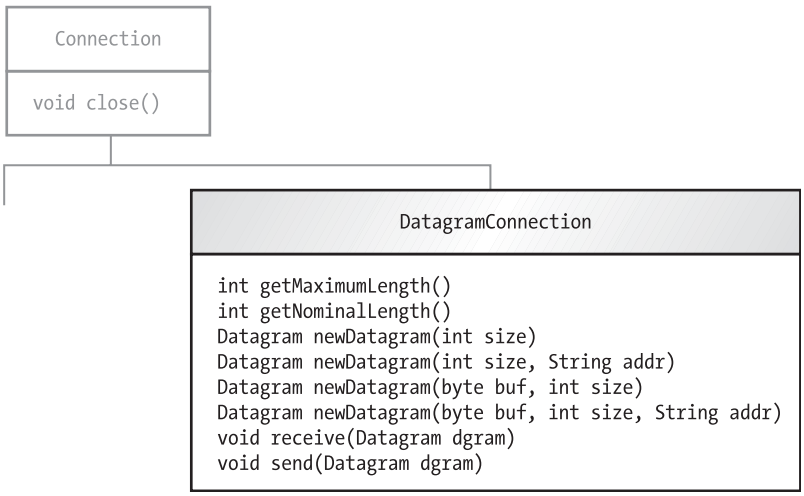


Figure 10-4. *The DatagramConnection interface*

The URL string passed to `Connector`'s `open()` method contains both the host name and port of the opposite end of the datagram connection. If datagram connections are not supported by a MIDP implementation, an exception will be thrown from the `open()` method.

All data is exchanged using `Datagrams`. To send a datagram, first ask the `DatagramConnection` to create one for you using one of the `newDatagram()` methods. Then write some data into it and pass it into the `send()` method of `DatagramConnection`. Receiving a datagram is almost as easy. You just call `receive()`, which blocks until a datagram is received.

In essence, `Datagram` is a wrapper for an array of bytes that are the payload of the datagram. You can retrieve a reference to this byte array by calling `getData()`. Keep in mind, however, that the data for the `Datagram` may be only a subset of the data in the array. You can find the array offset and length of the actual data by calling `getOffset()` and `getLength()`.

Interestingly, `Datagram` is an extension of both the `DataInput` and `DataOutput` interfaces, so it's possible to read and write data within a single `Datagram` as though it were a stream.

Datagram connections are represented by the `UDPDatagramConnection` interface, an extension of the `DatagramConnection` interface. `UDPDatagramConnection` adds two new methods, `getLocalAddress()` and `getLocalPort()`. You can use these methods to find out the originating point of datagrams sent using the connection.

Other Connection Types

Although the MIDP 2.0 specification requires only HTTP and HTTPS connections, it suggests that implementations support socket, server socket, and secure socket connections. The API provides appropriate interfaces for these connections. Devices may also choose to implement access to serial ports through the generic connection framework. Table 10-1 details the additional connection types, their supporting connection interfaces, and example connection strings. For more detailed information, see the API documentation for the corresponding interface.

Table 10-1. *Optional Connection Types*

Type	Interface	Example
Socket	`SocketConnection`	`socket://jonathanknudsen.com:79`
Server socket	`ServerSocketConnection`	`socket://:129`
TLS or SSL socket	`SecureConnection`	`ssl://jonathanknudsen.com:79`
Serial port	`CommConnection`	`comm:com0;baudrate=19200`

Responding to Incoming Connections

You may be used to thinking of mobile phones as client devices, but they may be full-fledged networked citizens, with the ability to receive incoming network connections. Although `ServerSocketConnection` provides the ability to listen for incoming socket connections, it can only be active while a MIDlet is actually running.

A typical server loop, listening for incoming socket connections on port 80, looks something like this:

```
ServerSocketConnection ssc;
ssc = (ServerSocketConnection)Connector.open("socket://:80");
boolean trucking = true;
while (trucking) {
  SocketConnection sc = (SocketConnection)ssc.acceptAndOpen();
  // Handle the client connection sc.
}
```

MIDP allows MIDlets to be launched in response to incoming network connections. The name for this technique is *push*. You could, in theory, create a web server MIDlet, although in practice a mobile phone is probably a poor platform for a web server. A more likely example would be an SMS MIDlet, something built using JSR 120, the Wireless Messaging API. Assuming the MIDlet was configured correctly, incoming SMS messages would cause the MIDlet to be launched to handle the connection.

A MIDlet may register for push connections in two ways: it can register at runtime using static methods in `javax.microedition.io.PushRegistry`, or it can register at install time using special entries in the application descriptor (JAD file). The important thing to remember is that the push registry has a lifetime beyond your MIDlet (in fact, even beyond multiple device reboot cycles). It is part of the MIDlet management software that runs on the device. When a MIDlet registers for push notifications, the device software is obligated to listen for incoming network connections and launch your MIDlet if the appropriate connection is made.

Inside your MIDlet, you don't have to do anything different to catch the incoming connection. All you do is call `Connector.open()` with the appropriate network listening string.

Let's say, for example, that you had created a web server in a MIDlet and called it `PatchyMIDlet`. (The source code for this book, available from `http://www.apress.com/`, includes `PatchyMIDlet`; it sends a randomly selected text message in response to incoming requests.) This MIDlet responds to incoming socket connections on port 80 (the default HTTP port). If you wanted to register the MIDlet at runtime, you'd do this in the code somewhere:

```
PushRegistry.registerConnection("socket://:80", PatchyMIDlet, "*");
```

The first two parameters are pretty clear—any incoming socket connections on port 80 should launch `PatchyMIDlet`. The third parameter is a filter that will be applied to incoming connections. In this case, we accept all incoming connections with the * wildcard. Other possibilities would be to restrict incoming connections to a single IP address or a range of addresses.

Remember, the results of the call to `registerConnection()` persist beyond the lifetime of the MIDlet. Even after the MIDlet has been destroyed, the MIDlet management software on the device is watching out for incoming socket connections on port 80. If a connection is received, `PatchyMIDlet` will be launched. The push registry doesn't actually do anything with the incoming connection; it just detects it and launches a registered MIDlet to respond. It's the MIDlet's responsibility to accept the incoming connection. To find out whether it has been launched by the push registry or the user, the MIDlet can call `PushRegistry`'s `listConnections()` method, passing `true` for the `available` parameter. The method will then return a list of connections that have input available. If this list is empty, then the MIDlet must have been launched by the user, not by an incoming connection.

Instead of a MIDlet registering push connections at runtime, it's much more likely that the push registrations would be contained in the application description for the MIDlet suite containing `PatchyMIDlet`. Thus, the push registration would be performed at installation time so that the user would never need to run the MIDlet manually. In this case, the MIDlet descriptor would contain a line like this:

```
MIDlet-Push-1: socket://:80, PatchyMIDlet, *
```

The parameters are exactly the same. The push registration is made when the MIDlet suite is installed. If the MIDlet cannot be registered (for example, some other application might already be listening for incoming socket connections on port 80), then the MIDlet suite will not be installed. Multiple push registrations are listed in the descriptor using ascending numbers: `MIDlet-Push-1`, `MIDlet-Push-2`, and so on.

The J2ME Wireless Toolkit version 2.2 allows you to register and test push connections easily. Just click the Settings button, and then choose the Push Registry tab. If you downloaded the source code for this book, you'll see an entry for `PatchyMIDlet`. Figure 10-5 shows this entry.

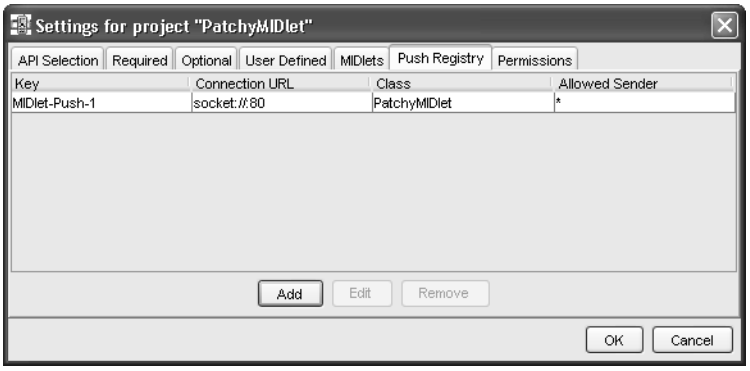


Figure 10-5. *The push registry entry for PatchyMIDlet*

To test the push notification, you'll have to package the application, and then deploy it on the WTK 2.2 emulator. First choose Project TRA Package ➤ Create Package to package the project into a MIDlet suite JAR. Then choose Project ➤ Run via OTA from the KToolbar menu. You'll see the emulator pop up, showing its Application Management Software (AMS). Select Install Application, and then accept the URL that is supplied. KToolbar contains a small OTA server; the URL is automatically preloaded when you select Run via OTA. You will see a series of other prompts about installing the application; just say yes to everything. Eventually the installation succeeds and you will see the MIDlet `PatchyMIDlet` listed in the emulator's menu. The emulator is now running, listening for incoming connections, even though no MIDlets are running.

Now test `PatchyMIDlet` by pointing your browser to `http://localhost/`. `PatchyMIDlet` will be launched and will send a response to the browser. (The emulator will ask if it's okay to send data back on the network; you'll have to say yes.) Figure 10-6 shows the emulator running `PatchyMIDlet` and a browser showing its output.

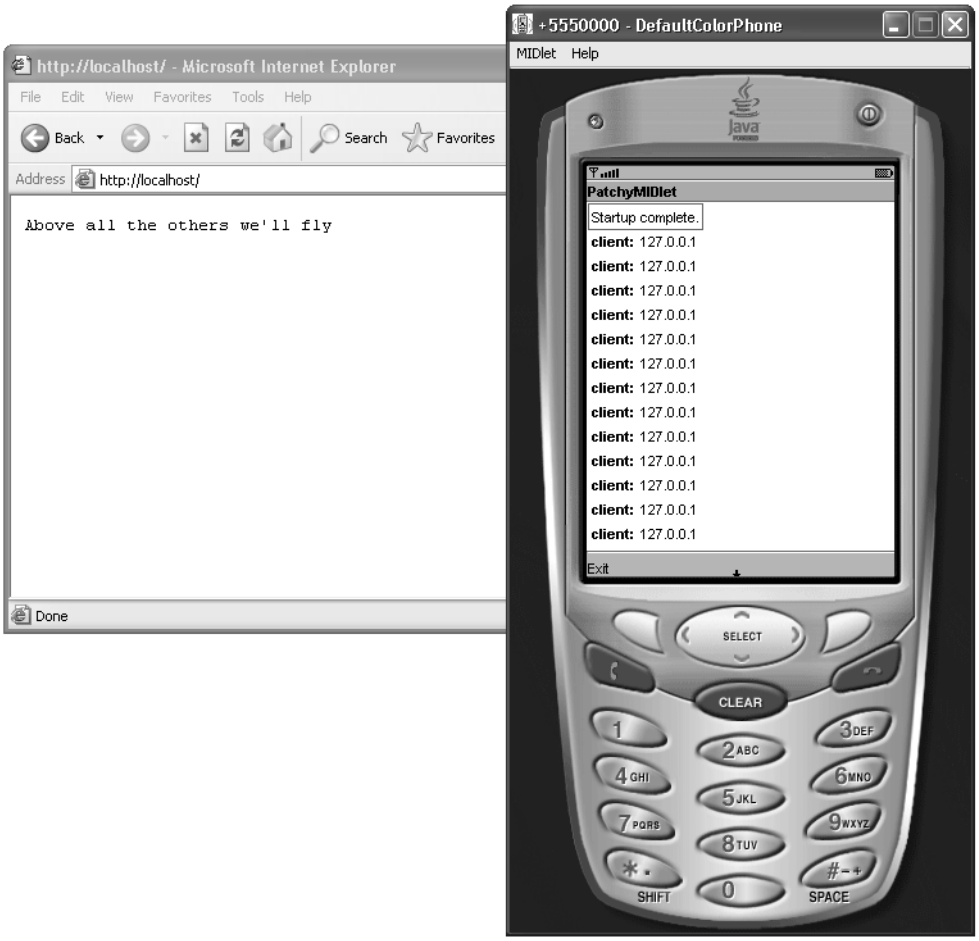


Figure 10-6. *PatchyMIDlet, a small web server*

Run via OTA is an excellent tool for testing your MIDlet's installation behavior rather than its runtime behavior. Just remember that you need to package the MIDlet first because the toolkit's small OTA distributes the MIDlet suite JAR file from the project's `bin` directory.

`PushRegistry` contains several other static methods that are related to network registrations. The `getMIDlet()` and `getFilter()` methods return the MIDlet name and filter for a given network connection string. The `listConnections()` method returns a string array containing all the registered network connection strings. Finally, to remove a connection-to-MIDlet mapping, use `unregisterConnection()`.

Permissions for Network Connections

MIDP 2.0 includes a security framework that is designed to prevent MIDlets from running up your phone bill by making unauthorized network connections. As we discussed in Chapter 3, network access in MIDP is guarded by permissions and protection domains. Here are the permission names defined by MIDP:

- `javax.microedition.io.Connector.http`
- `javax.microedition.io.Connector.https`
- `javax.microedition.io.Connector.datagram`
- `javax.microedition.io.Connector.datagramreceiver`
- `javax.microedition.io.Connector.socket`
- `javax.microedition.io.Connector.serversocket`
- `javax.microedition.io.Connector.ssl`
- `javax.microedition.io.Connector.comm`
- `javax.microedition.io.PushRegistry`

These permissions have names corresponding to the API that they protect. All of these permissions, except one, protect connection types, which are accessed via the `javax.microedition.io.Connector` class, hence the prefix on those permission names. The very last permission refers to the push registry and shares its name with the `PushRegistry` class.

When you run a MIDlet suite in the toolkit, it runs in the untrusted domain by default. In the untrusted domain, HTTP and HTTPS connections are allowed if the user grants permission. You can see this when you run a MIDlet that attempts a network connection. Figure 10-7 shows how the emulator asks the user for permission and allows the user to make the decision stick for the remainder of the session.

You can indicate the necessary and optional permissions used by your MIDlet suite by using the `MIDlet-Permissions` and `MIDlet-Permissions-Opt` descriptor attributes. (In the J2ME Wireless Toolkit, you can set permissions in the descriptor by choosing Settings, and then clicking the Permissions tab.)

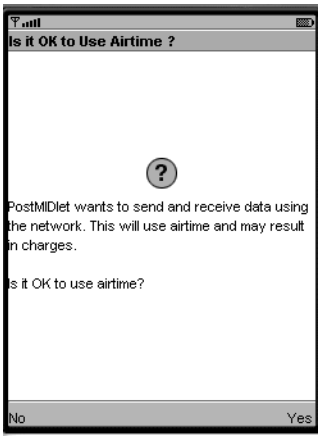

Is it OK to Use Airtime ?
PostMIDlet wants to send and receive data using the network. This will use airtime and may result in charges.
Is it OK to use airtime?
No
Yes

Figure 10-7. *The emulator asks for the user's permission for network connections.*

Summary

Networking on the MIDP platform is based on a generic connection framework. MIDP mandates the support of HTTP. You can perform GET, HEAD, or POST requests with just a few lines of code. HTTP session handling is also feasible. MIDP also requires support for HTTPS in addition to HTTP and formalizes the connection strings and APIs for handling additional connection types. Implementations are free to support additional connection types; datagrams, sockets, server sockets, and serial port communications are some of the possibilities. MIDP's security architecture protects users from unauthorized network use.

CHAPTER 11

Wireless Messaging API

Using the Internet on your cell phone is fun, but it can be quite costly. Connection time is billed per minute or per packet, and this can add up fast to a fat bill. In most cases, a lower cost alternative is readily available. Called Short Message Service (SMS), it is often offered by national carriers as text messaging.

The Wireless Messaging API, or WMA, is an optional API that enables MIDP applications to leverage the utility of SMS. In addition, the API can be used for receiving and processing Cell Broadcast Service (CBS) messages. WMA 2.0, recently finalized, adds the support for Multimedia Message Service (MMS) messages. It becomes easy for MIDP applications to send and receive images, video, and other multimedia content.

Ubiquitous SMS

Short Message Service, or SMS, is one of the most widely available and popular services for cell phone users. Often sold as text messaging service, it is the ability to send short messages between phone users.

SMS has its origin back in the day when cellular phones were expensive and operated over mostly analog-based technology. Even though the voice portion of a phone call is circuit switched over an analog network, the control network for the call is digital, and it has spare capacity to carry a small text message.

Since those early days, SMS has undergone some major technical changes under the hood. The user experience, however, remains the same.

The ubiquitous nature of SMS means that it is supported worldwide on cellular networks of (almost) any technology, including but not limited to TDMA, CDMA, WCDMA, GSM, GPRS, CDMA2000-1X, CDMA2000-MX, and EDGE.

SMS: The Killer App for Wireless

The ability to send short text messages (up to 160 characters in most cases) between cell phone users inexpensively is compelling enough. The possibility to send messages directly between J2ME applications running on cellular phones is even more exciting. Messages can now be sent and received between phones without

- Having Internet access from the phone (potentially additional cost service)
- Going through an intermediary server (potentially from the carrier at additional cost)
- Being restricted in terms of routing by the carrier's network

In most cases, if you can make a call to an endpoint (a cell phone), then you can also send an SMS message!

Unlike a cell phone call, however, a message is not lost if the receiving phone is not available when the message is sent. SMS messages are sent through a store-and-forward network, and messages will queue up until the receiving device is available. This can be used to great advantage for some applications. Through SMTP gateway services, it is even possible to send SMS messages using e-mail and receive SMS messages as e-mail.

The possible applications are unlimited. Chat-type applications are the obvious for SMS, but interactive gaming, event reminders, e-mail notification, mobile access to corporate resources, and informational service are a sample of other opportunities.

WMA makes SMS available to MIDP developers. In other words, WMA provides a generalized direct point-to-point communications mechanism for MIDP applications.

■ **Note** SMS can also be used in conjunction with the push registry to launch MIDlets on your cell phone. See Chapter 10 for more details on push registry operations.

WMA and SMS

When a message is sent and received via WMA, there are two major benefits. First, the message can now be significantly larger in size than a single SMS message. Second, the content is no longer restricted to simple text messages. Under the hood, the WMA API will do the following:

- Encode a binary message and transmit it through SMS.
- Cut up a long message into segments, and send it via multiple (up to three) SMS messages.

Two current and finalized JSRs are relevant to WMA, and these are listed in Table 11-1.

Table 11-1. *The WMA JSRs*

JSR	Name	URL
120	Wireless Messaging API	`http://jcp.org/jsr/detail/120.jsp`
205	Wireless Messaging API 2.0	`http://jcp.org/jsr/detail/205.jsp`

JSR 120 actually describes WMA 1.1. Almost all devices that support WMA today have WMA 1.1 implementations.

With JSR 205, support of multimedia messaging is added. This is the crux of WMA 2.0. It is the ability to send large binary messages consisting of multiple parts. These messages are perfect for carrying images, sound, video, or multimedia presentations.

WMA API

WMA is built on top of CLDC (or CDC) and requires only the Generic Connection Framework (GCF) of CLDC 1.0. Therefore, WMA will work well on both CLDC 1.0 and CLDC 1.1 devices.

Like `SocketConnection` and `DatagramConnection` in the GCF, you get a `MessageConnection` by passing in an address to the `connect()` method. Unlike these other connections, however, you cannot open an input or output stream from it. `MessageConnections` are only used to send and receive messages. All the interfaces and classes in WMA are part of the `javax.wireless.messaging` package.

WMA's API is built around the GCF. Figure 11-1 shows the new APIs in WMA and how they relate to the GCF.

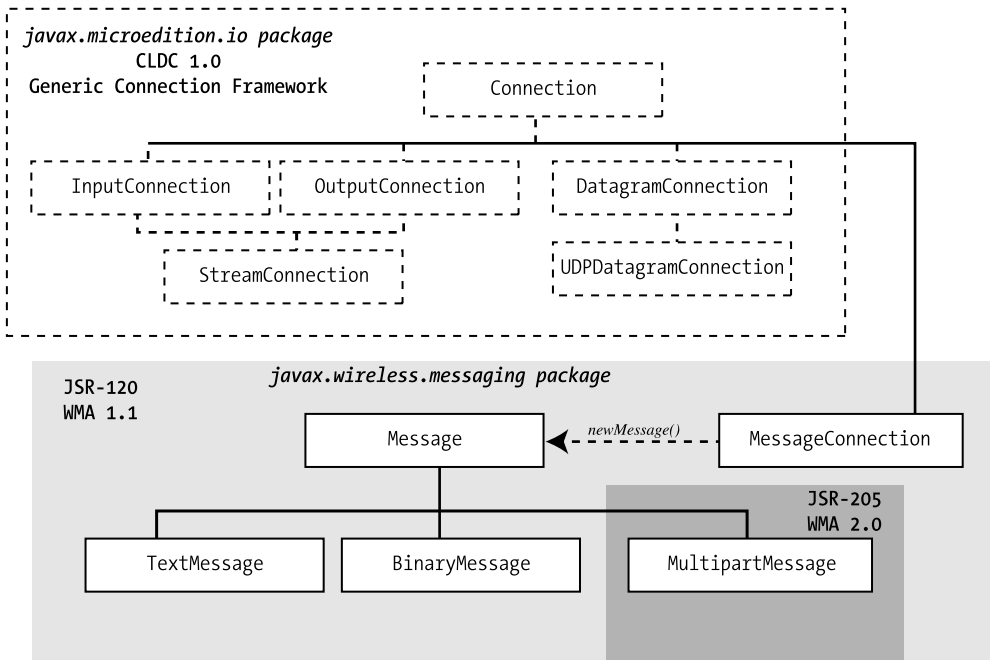


Figure 11-1. *Extending the GCF with WMA APIs*

A typical call to open a `MessageConnection` for sending or receiving message may be

```
MessageConnector msgConn = (MessageConnector) Connector.open("sms://5550001:1234");
```

This will create a client mode connection. A client mode connection can only be used to send messages. Messages sent through this connection will be destined for phone number `5550001`, port 1234.

■ **Note** WMA encompasses the concept of a port. It allows multiple applications to accept messages on the same device. It also enables the device to differentiate between SMS messages destined for a WMA application and standard text messages. The cost of this is a few bytes of data at the beginning of an SMS message, resulting in only 152 characters being available for text in most cases.

You can also create a server mode connection. Instead, if you were to open the connection using the following:

```
MessageConnector msgConn = (MessageConnector) Connector.open("sms:// :1234");
```

you would end up with a server mode connection. Typically, server mode connections are used to receive incoming messages. However, server mode connections can actually be used to send messages as well.

Once you have a `MessageConnection`, you can use it to

- Create messages.
- Receive messages (server mode only).
- Send messages.
- Obtain segmentation information on a message.

If you want to send messages, you first need to create an empty one. With an empty message, you can then fill it up and send it. To create the empty message, you must use a `MessageConnection`.

■ **Note** JTWI is a godsend for WMA standardization. JTWI 1.0 requires that a compatible device support WMA 1.1 APIs. In particular, SMS support on GSM or WCDMA (UMTS) phones is mandated. MIDP `PushRegistry` support (see Chapter 10) for incoming SMS connections is also required. If access to GSM cell broadcast is available for Java APIs, it must be available through the WMA 1.1 APIs. Therefore, you can be right at home with wireless messaging whenever you're working on a JTWI phone.

Creating New Messages

A `MessageConnection` is the class factory for messages. There is no way to create a message other than using a `MessageConnection`. Figure 11-1 shows that a message is created using the `newMessage()` method, which actually has two variations:

```
Message newMessage(String messageType);
Message newMessage(String messageType, String address);
```

The second form is a code saver when you are using server mode connections. Since messages created with a server mode connection do not have a destination address, you can create a new message and set its destination address with one single call.

From Figure 11-1, you can see that there are three types of messages: `TextMessage`, `BinaryMessage`, and `MultipartMessage`. `MultipartMessage` will only be available if your MID implements WMA 2.0. To specify a message type for the `newMessage()` factory method, you can use the predefined constants `MessageConnection.TEXT_MESSAGE`, `MessageConnection.BINARY_MESSAGE`, and `MessageConnection.MULTIPART_MESSAGE`.

Sending Binary SMS Messages

SMS can be used to send text or binary messages. To send a binary message using WMA, first create an empty message using the `newMessage()` method of the open `MessageConnection`. You need to specify `MessageConnection.BINARY_MESSAGE` for its type.

Next, get the binary data into a byte array (possibly using one of the IO stream classes). Then set the payload of the `BinaryMessage` with the data in the byte array using

```
public void setPayloadData(byte [] data);
```

Binary messages are typically limited to 133 bytes per SMS message. For longer messages, WMA will take care of separating the message into segments for you (see the warning that follows).

You can use the following method of your `MessageConnection` instance to determine the number of SMS messages that a particular binary message may span:

```
int numberOfSegments(Message msg);
```

■ **Warning** WMA requires an implementation to support messages spanning three segments. This means that you should not depend on WMA to send and receive any binary messages longer than 381 bytes (unless you know for sure that both the sender's and receiver's WMA implementation support longer messages).

After the payload and the receiving address has been set on the message, you are ready to send it using this `MessageConnection` method:

```
void send(Message msg) throws IOException, InterruptedIOException;
```

You will catch an `IOException` if there is a network problem or the `MessageConnection` is already closed. The `InterruptedIOException` will be thrown if the `MessageConnection` is closed during the sending operation or a timeout occurs.

As with any network operations, you should call `send()` on a separate non-GUI thread to avoid hanging the GUI.

■ **Tip** Remember that if you are using a server mode `MessageConnection` to send messages, you must set the recipient address explicitly on each new message that you create— before you call `send()`. If you are reusing an incoming message for replies, however, this is not necessary. You just need to set a new payload (the reply). The address of an incoming message is already filled in with the sender's address.

Sending Text SMS Messages

Sending a text message is similar to sending binary messages. First, create an empty message using `MessageConnection`'s `newMessage()` method, specifying `MessageConnection.TEXT_MESSAGE` as its type.

Next, set the payload with the text string that you want to send:

```
public void setPayloadText(String data);
```

Finally, use the `send()` method of `MessageConnection` to send the message. Here is a code fragment that you may use to open a connection and send an SMS text message:

```
MessageConnection conn =
   (MessageConnection) Connector.open("sms://5550001:1234");
TextMessage txtmessage = (TextMessage) conn.newMessage(
MessageConnection.TEXT_MESSAGE);
txtmessage.setPayloadText(msgString);
conn.send(txtmessage);
```

Just like binary messages, you can also send large text messages that span multiple SMS messages. The WMA API will handle segmentation at the sending end and reassembly at the receiving end. However, some character encoding (namely UCS-2) limits the length of each SMS text message to only 72 characters (66 available due to the port information used by WMA). To accommodate this, the maximum sized text message that you can send safely is 189 characters (3 SMS segments). See JSR 205 for details of payload length calculation if you are interested.

Receiving SMS Messages

To receive messages using a `MessageConnection`, you have two choices:

- Use a blocking `receive()` method.
- Implement a listener callback to be notified when a message arrives.

When using the blocking `receive()` method, you typically will be managing your own threads. Using a listener allows you to code the logic in a callback method, without creating and managing additional threads. You can choose either approach.

Calling the Blocking receive() Method

The blocking `receive()` method is on the `MessageConnection` interface. This method will block the incoming call until an incoming message is available or until the connection is closed. The syntax for `receive()` is as follows:

```
public Message receive() throw IOException, InterruptedIOException
```

`IOException` will be thrown if an error is encountered during the receiving process, if the connection is closed, or if the method is called on a connection opened in the client mode (send only).

Since `receive()` is a blocking call, it should always be called on its own thread. A common approach is to create a "receiver thread" to receive messages in an application.

`InterruptedIOException` is thrown if the connection is closed while the call is still blocking. Closing a `MessageConnection` is a way to release a receiver thread that may be blocked waiting for incoming messages.

Typical message receive code when using the blocking `receive()` looks like this:

```
  conn = (MessageConnection) Connector.open("sms://5550001:1234");
  msg = conn.receive(); // Blocking here
  mSenderAddress = msg.getAddress();  // Get info from message
  if (msg instanceof TextMessage) {
 String msgReceived = ((TextMessage)msg).getPayloadText();

  // Do something with the message here

 } else if (msg instanceof BinaryMessage) {
 byte [] msgReceived = ((BinaryMessage)msg).getPlayloadData();
   // do something with the binary message here

 }
  }
```

When working with the payload of incoming messages, the following method on the `BinaryMessage` interface is used to access the content of the binary message:

```
public byte [] getPayloadData();
```

On a `TextMessage`, the following method is used to access the content of the text message:

```
public String getPlayloadText();
```

A Nonblocking Approach to Receiving SMS Messages

`MessageConnection` supports a nonblocking, event listener–based way for receiving SMS messages. To use this, you will need to do the following:

1. Register a `MessageListener` with the `MessageConnection`.
2. Handle the callback on the `notifyIncomingMessage()` method of the `MessageListener` interface.

First, add a `MessageListener` using the `setMessageListener()` method on the `MessageConnection`:

```
public void setMessageListener(MessageListener lis) throws IOException;
```

The object that you register as a listener must implement the `MessageListener` interface. Only one listener can be registered at a time for a connection; any new registration will displace the old one. The `MessageListener` interface has a single callback method:

```
public notifyIncomingMessage(MessageConnection conn);
```

The callback is performed by WMA on a system thread, and the `notifyIncomingMessage()` method must return as soon as possible. This means that any work should be performed by another thread. In fact, WMA mandates that even the call to the `receive()` method (to pick up the incoming message) must be performed in another thread. This will require careful concurrent programming using Java's synchronization primitives. In addition, the WMA implementation may perform simultaneous callback on multiple threads if messages are arriving concurrently. This means that you need to be careful to synchronize access to any variables outside of your thread's `run()` method.

Even though this nonblocking approach is attractive conceptually, it is often simpler to use the blocking receive call alternative. The final example in this chapter (see Listing 11-3) shows some code using this nonblocking approach.

Examining Message Headers

In addition to the binary or text payload, other interesting information appears in the message header.

You can get access to the address information using the following methods on the `Message` interface:

```
public String getAddress();
public void setAddress(String addr);
```

The Message interface is the super interface of both TextMessage and BinaryMessage, and the preceding methods are available for both types of messages. The getAddress() method returns the recipient's address if it is an outgoing message, or the sender address if it is an incoming message. In fact, incoming messages can be reused for replies by just setting a new payload.

The setAddress() method can be used to set the destination address for an outgoing message. The destination address is set automatically when you're using a client mode MessageConnection to create new messages. You will only need to call setAddress() if you're using a server mode MessageConnection to create new messages.

Another method on the Message interface provides access to the timestamp on the message:

```
public Date getTimestamp();
```

This getTimestamp() method will return the timestamp on the message if it is available.

Receiving CBS Messages

Cell Broadcast Service, or CBS, is a carrier version of SMS. It enables a cell phone operator to broadcast messages to a group of cell phone users. A WMA application can only receive CBS messages.

There are no additional interfaces or classes for handling of CBS. You use the same mechanism as receiving SMS messages. However, the MessageConnection for CBS can only be opened in the server (receiver) mode, since it is not possible to send CBS messages. For example:

```
conn = (MessageConnection) Connector.open("cbs://:12345");
msg = conn.receive(); // Blocking for message
```

The digits 12345 in this case do not refer to a WMA-managed port as in SMS; instead, they serve as a message identifier. Message identifiers are a CBS-specific concept. They may represent different information channels that you can subscribe to. You need to consult your carrier for the available message identifiers if you are developing software to process CBS messages.

Do not call send() on a CBS MessageConnection. Only phone network operators can broadcast CBS messages. If you do call send(), you will get an IOException. Since CBS messages do not carry any timestamp, calling getTimeStamp() on the message always returns null.

Working with SMS APIs

Let's put some of this to work. SMSMIDlet is a MIDlet that can send and receive SMS messages. The GUI of SMSMIDlet is shown in Figure 11-2.

SMSMIDlet can be used to receive or send SMS messages. SMSMIDlet listens at port 1234. If the SMSMIDlet receives an SMS text message containing the word "red", an image with a red background will be displayed by the MIDlet. If the SMS text message received contains the string "blue", an image with a blue background will be displayed.

In Figure 11-2, you can enter the address that you want to send SMS messages to into the "Connect to:" text field. Using the menu, you can then send either a "red" or "blue" SMS message to the recipient.

Figure 11-2. *GUI of SMSMIDlet*

The code for `SMSMIDlet` is shown in Listing 11-1.

Listing 11-1. *A MIDlet to Send and Receive SMS Messages—SMSMIDlet*

```
import javax.microedition.midlet.*;
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.wireless.messaging.*;

import java.io.IOException;
```

```
public class SMSMIDlet
extends MIDlet
implements CommandListener, Runnable {
  private Sender mSender = null;
  private Thread mReceiver = null;
  private Command mExitCommand = new Command("Exit", Command.EXIT, 2);
  private Command mRedCommand = new Command("Send Red", Command.SCREEN, 1);
  private Command mBlueCommand = new Command("Send Blue", Command.SCREEN, 1);

  private Display mDisplay = null;
  protected ImageItem mColorSquare = null;
  protected Image [] mImages = new Image[2];
  protected Image waitImage = null;
  private String mPort = "1234";
  private TextField mNumberEntry= null;
  private Form mForm = null;

  private String mSenderAddress = null;
  public SMSMIDlet() {
       mSender = Sender.getInstance();
  }

  public void commandAction(javax.microedition.lcdui.Command c,
  javax.microedition.lcdui.Displayable d) {
       if (c == mExitCommand) {
      if (!mSender.isSending()) {
      destroyApp(true);
      notifyDestroyed();
      }
       } else if (c == mRedCommand) {
      String dest = mNumberEntry.getString();
      if (dest.length() > 0)
      mSender.sendMsg(dest, mPort, "red");

       } else if (c == mBlueCommand) {
      String dest = mNumberEntry.getString();
      if (dest.length() > 0)
       mSender.sendMsg(dest, mPort, "blue");
       }
 }
```

```
protected void destroyApp(boolean param) {
     try {
    mEndNow = true;
    conn.close();
     } catch (IOException ex) {
    System.out.println("destroyApp caught: ");
    ex.printStackTrace();

     }

}

protected void pauseApp() {
}

protected void startApp() {
     if (mForm == null) {
    mForm = new Form("SMSMIDlet");
    mNumberEntry = new TextField("Connect to:",
    null, 256, TextField.PHONENUMBER);
    try {
    mImages[0] = Image.createImage("/red.png");
    mImages[1] = Image.createImage("/blue.png");
    waitImage = Image.createImage("/wait.png");
    } catch (Exception ex) {
    System.out.println("startApp caught: ");
    ex.printStackTrace();
      }

    mColorSquare = new ImageItem(null, waitImage,ImageItem.
    LAYOUT_DEFAULT, "colored square");
    mForm.append(mNumberEntry);
    mForm.append(mColorSquare);
    mForm.addCommand(mExitCommand);
    mForm.addCommand(mRedCommand);
    mForm.addCommand(mBlueCommand);

    mForm.setCommandListener(this);
     }
     Display.getDisplay(this).setCurrent(mForm);
     startReceive();
}

private void startReceive() {
     if (mReceiver != null)
    return;
```

```
        // Start receive thread
        mReceiver = new Thread(this);
        mReceiver.start();
    }
    private boolean mEndNow = false;
    private MessageConnection conn = null;
    public void run() {
        Message msg = null;
        String msgReceived = null;
        conn = null;
        mEndNow = false;
        /** Check for sms connection. */
        try {
       conn = (MessageConnection) Connector.open("sms://:" + mPort);
       msg = conn.receive();
       while ((msg != null) && (!mEndNow)) {

       if (msg instanceof TextMessage) {

      msgReceived = ((TextMessage)msg).getPayloadText();
      if (msgReceived.equals("red")) {
        Display.getDisplay(this).callSerially(new SetRed());
      } else if (msgReceived.equals("blue")) {
        Display.getDisplay(this).callSerially(new SetBlue());
      }
       }

       msg = conn.receive();
       }
        } catch (IOException e) {
         // Normal exit when connection is closed
        }

    }
    class SetRed implements Runnable {
        Display disp = null;

        public void run() {
       mColorSquare.setImage(mImages[0]);
        }
    }
    class SetBlue implements Runnable {
        public void run() {
       mColorSquare.setImage(mImages[1]);
        }
    }
}
```

Creating an Independent Receive Thread

SMSMIDlet actually uses a separate receive thread to process incoming messages. This thread will also set the ImageItem of the GUI with a different Image depending on incoming SMS messages. The startReceive() method in Listing 11-1 contains the code that starts the receive thread. The run() method contains the logic of the receive thread. The blocking receive() call is used in this case. The mEndNow boolean flag stops the thread when the application is destroyed; see the destroyApp() implementation.

The receive thread opens a server mode MessageConnection on port 1234. When there are no incoming messages, the receive thread is blocked in one of the receive() methods. Upon receipt of a message, the text payload is extracted and compared to "red" or "blue". Then Display.callSerially() updates the image shown on the GUI. Two helper classes, SetRed and SetBlue, are used when calling this method.

Sending SMS Messages

Listing 11-2 shows the class, called Sender, that is used to send SMS messages. SMSMIDlet maintains an instance of this class called mSender. The instance is used to send SMS messages when the user selects either Send Red or Send Blue from the menu.

Listing 11-2. *Sending SMS Message with Sender*

```
import javax.microedition.io.*;
import javax.wireless.messaging.*;

import java.io.IOException;

public class Sender implements Runnable {
  private static Sender inst = new Sender();
  private Sender() {
  }
  public static Sender getInstance() {
       return inst;
  }
  private String mReceiver = null;
  private String mPort = null;

  private String msgString = null;
  private boolean mSending = false;
  public void sendMsg(String rcvr, String port, String msgText) {
     if (mSending) return;
     mReceiver = rcvr;
     mPort = port;
     msgString = msgText;
  Thread th = new Thread(this);
    th.start();
  }
```

```
  public boolean isSending() {
    return mSending;
  }
  // Send the color message
  public void run() {
    mSending = true;
    try {
      sendSMS();
    } catch (Exception ex) {
       System.out.println("run() caught: ");
       ex.printStackTrace();
    }
   mSending = false;


  private void sendSMS() {

   String address = "sms://" + mReceiver + ":" + mPort;

   MessageConnection conn = null;
    try {
       /** Open the message connection. */
       conn = (MessageConnection) Connector.open(address);
      TextMessage txtmessage = (TextMessage) conn.newMessage(
      MessageConnection.TEXT_MESSAGE);
      txtmessage.setAddress(address);
       txtmessage.setPayloadText(msgString);
      conn.send(txtmessage);
    } catch (Throwable t) {
      System.out.println("Send caught: ");
      t.printStackTrace();
     }
     if (conn != null) {
      try {
      conn.close();
      } catch (IOException ioe) {
        System.out.println("Closing connection caught: ");
      ioe.printStackTrace();
      }
    }
  }
}
```

In Listing 11-2, `Sender` is a singleton; the static `getInstance()` factory method is used to get the one and only instance. The `sendMsg()` method is used by `SMSMIDlet` to send the SMS message. It assigns the incoming arguments to member variables, and then starts a thread to send the message. The `mSending boolean` flag is used to avoid reentrant calls and to stop the MIDlet from shutting down if message sending is in progress. The actual work of sending SMS messages is performed in the `sendSMS()` method. The `sendSMS()` method is always called from a new thread. `sendSMS()` opens a new `MessageConnection` using a specified address and sends a text message to the destination.

Testing SMSMIDlet with WTK 2.x WMA Console

You can easily test `SMSMIDlet`, or any SMS application, using a utility called the WMA console in WTK 2.x. To access the WMA console, select File ➤ Utilities from KToolbar. Then click the Open Console button in the WMA box.

To test `SMSMIDlet`, first start an instance in an emulator. Answer yes to the security question when it starts up. Note on the title bar of the emulator that a phone number, beginning with a + (plus sign), has been assigned to the emulator. By default, it will be `+5550000`. This is the address of the emulator instance.

Now, start the WMA console. You will note that the WMA console is also assigned a phone number beginning with a + sign. Click the Send SMS button. Select the address of the emulator instance on the `Text SMS` tab, enter **1234** into the `Port` box, and then enter **red** for the message. Click the Send button. Note that the `SMSMIDlet` instance now displays an image with a red background. Try sending an SMS message containing "blue" and observe how the `SMSMIDlet` instance changes the graphics to a blue background.

Next, enter the address of the WMA console into the "Connect to:" text field of the `SMSMIDlet` instance. Then select Send Red from the menu of `SMSMIDlet`. Note that the console displays a message to indicate receipt of the SMS message. Figure 11-3 shows the WMA console interacting with `SMSMIDlet`.

Instead of using the WMA console, you can also start two emulator instances of `SMSMIDlet` and send SMS messages between them.

Figure 11-3. *Sending and receiving SMS messages using SMSMIDlet and WMA console*

Multimedia Messaging with WMA 2.0

The major addition in the WMA 2.0 API is the availability of multipart messages. Multipart messages are specially designed to support the new Multimedia Message Service. MMS is frequently found in 2.5G and 3G phone networks.

Essentially, MMS enables you to send and receive large binary messages in a manner similar to SMS. The messages supported can contain multiple message parts; each of the parts can contain text, an image, an audio clip, a video clip, or other multimedia content. For example, a complete multimedia presentation can be sent in a single MMS, containing a SMIL script and the individual media elements referenced by the presentation.

At the time of writing, there are very few phones supporting WMA 2.0. Since 2.5G and 3G networks are not yet in widespread deployment, the availability of MMS is still scarce.

The Anatomy of a Multipart Message

Figure 11-4 shows what a multipart message looks like conceptually.

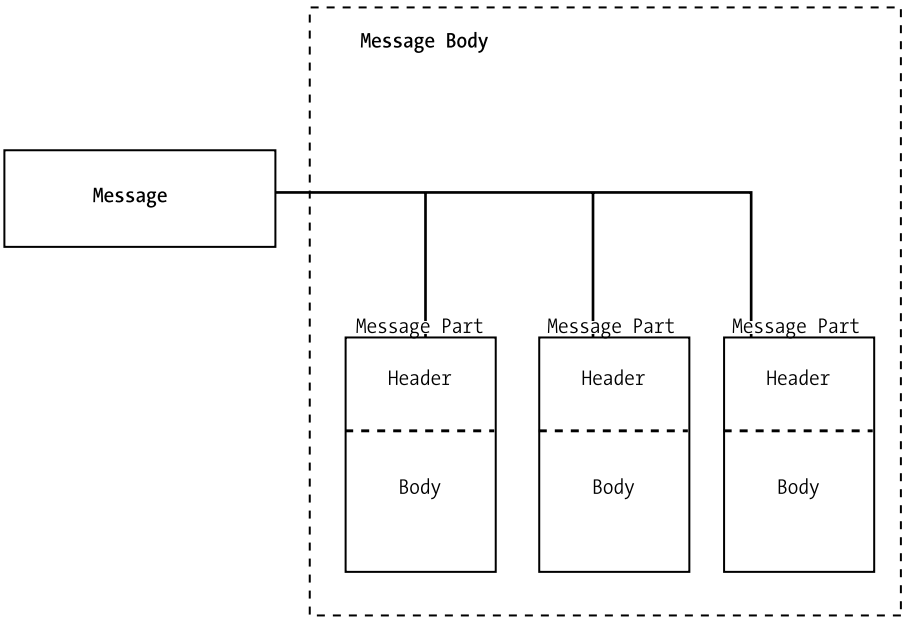


Figure 11-4. *Anatomy of a multipart message*

In Figure 11-4, the multipart message has the usual header and body found in all messages. However, the body itself contains many separate parts, called message parts. Each message part has its own header and content.

The type of each body part is specified in its header. Each body part can be of a MIME type that is supported by the communicating applications.

Working with Multipart Messages

A `MultipartMessage` is a subinterface of `Message`. The additional methods on the `MultipartMessage` interface deals with the additional features required by MMS messages.

First off, a multipart message differs from an SMS message in that it can have multiple recipients. Similar to e-mail, you can have multiple recipients for "to", "cc", and "bcc" fields. A message with multiple recipients can be sent to a Multimedia Message Service Center (MMSC) to be processed. The MMSC can then in turn send the message to all intended recipients.

Managing Addresses

The following methods are available for managing the addresses associated with a multipart message:

```
public String setAddress(String address);
public String getAddress();
public boolean addAddress(String type, String address);
public String [] getAddresses(String type);
```

The first two methods are inherited from the `Message` interface. `setAddress()` can be used to set the first "to" address for an outgoing message. Additional "to" addresses can be added using the `addAddress()` method. `addAddress()` can also be used to add "cc" and "bcc" recipients.

`getAddress()` will return the first "to" address on an outgoing message, and the "from" address from an incoming message. `getAddresses()` returns all the addresses associated with a address type, such as "cc", "bcc", "to", or "from".

You can remove all the addresses in an address type using this method:

```
public void removeAddresses(String type);
```

Remove all the addresses in the "to", "cc", and "bcc" fields of a message by using the following:

```
public void removeAddresses();
```

You can also be more selective and remove only a specific address:

```
public boolean removeAddress(String type, String address);
```

Content ID and Content Location

The content of each message part can have its own ID and location. This information is stored in the header of the message part. The content ID uniquely identifies a message part within the message, while the location can refer to the actual location where the content is stored (for example, a URL accessible over the Internet). The exact syntax of these two pieces of information and how they are used will depend on the application and/or the specific MMS implementation.

You can read the content ID and location using the following methods on the `MessagePart` interface:

```
public String getContentID();
public String getContentLocation();
```

The Start Content ID

For some applications, a particular message part in a message may contain the script or code to start a multimedia presentation. This is similar to the concept of a main class in Java programming. In order to signify that a particular message part can be used to start a presentation, its unique content ID can be designated as a start content ID. The following two methods help with this:

```
public String getStartContentId();
public void setStartContentId(String contentId);
```

Adding a Subject to the Message

MMS messages, like e-mail, can contain a subject header. There are two methods for working with subjects:

```
public String getSubject();
public void setSubject(String subject);
```

Working with Other Message Headers

Depending on the MMS implementation that you work on, there might be other header information that can be accessed. Consult JSR 205 for more details. The methods that access other headers are as follows:

```
public String getHeader(String headerField);
public void setHeader(String headerField, String headerValue);
```

Managing Message Parts

The payload of a multipart message is the collection of contained message parts. You can obtain any message part of a multipart message via its content ID:

```
public MessagePart getMessagePart(String contentID);
```

All the message parts of a multipart message can be obtained at once, as an array, using this code:

```
public MessagePart [] getMessageParts();
```

To delete a message part from a message, you can use any of the following:

```
public boolean removeMessagePart(MessagePart part);
public boolean removeMessagePartId(String contented);
public boolean removeMessagePartLocation(String contentLocation);
```

The first form is convenient if you already have a copy of the message part. Otherwise, if you have the content ID or the content location, you can use the other two variations to delete the message part.

Adding Message Parts to a Message

When sending messages, you must first use a `MessageConnection` to create a new multipart message. Next, you will follow these steps:

1. Create a new message part using the `newMessage()` class factory.
2. Set the message part's headers.
3. Populate the message part's content.
4. Add the part to the multipart message.
5. Repeat 1 to 4 for all the message parts.

Step 1 is identical to the SMS case. The next section shows you how to perform steps 2 and 3. Once you've created and populated a `MessagePart` and set the relevant headers, you can add it to a `MultipartMessage` using this method:

```
public void addMessagePart(MessagePart part);
```

Accessing Content of Message Parts

A message part consists of content (the payload) and header. The header contains MIME type information, the encoding used, the content ID, and the content location. The `MessagePart` class allows you to work with individual message parts. To create a new `MessagePart`, you can use one of its constructors:

```
public MessagePart(byte[] contents, int offset, int length, String mimeType,
  String contentId, String contentLocation, String encoding);
public MessagePart(byte[] contents, String mimeType, String contentId,
  String contentLocation, String encoding)
public MessagePart(InputStream is, String mimeType, String contentId,
  String contentLocation, String encoding);
```

The first two methods set the contents of the message part from a byte array, while the last one does so from an `InputStream` (for larger content such as audio or video). The first variant of the byte array methods allows you to specify an offset and length to extract part of the byte array as content. The second form uses the entire input byte array.

To access the content of a `MessagePart`, you can use the following:

```
public byte[] getContent();
public InputStream getContentAsStream();
```

For processing small-sized content, working with a byte array may be convenient. For very large multimedia content, especially audio and video, using `getContentAsStream()` can provide more usable access to the content.

MessagePart Header Information

You can use other methods of `MessagePart` to access header information:

```
public String getContentEncoding();
public String getMIMEType();
public String getContentID();
public String getContentLocation();
public int getLength();
```

The last method, `getLength()`, returns the length of the content in bytes.

A MIDlet to Send and Receive MMS

Putting the WMA 2.0 MMS API to work, the example presented in this section is a modification of the `SMSMIDlet`. The user interface is identical.

The major differences are as follows:

- The MIDlet is called `MMSMIDlet` and the sender class is called `MMSSender`.
- The MIDlet uses the nonblocking, event-driven notification mechanism to receive messages.
- Instead of just the text "red" or "blue" in an SMS message, the entire image to be displayed is sent as a `MessagePart` in a `MultipartMessage`.

First, Listing 11-3 shows the code for the `MMSMIDlet`.

Listing 11-3. *The MMSMIDlet for Sending and Receiving MMS*

```
import javax.microedition.midlet.*;
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.wireless.messaging.*;

import java.io.IOException;

public class MMSMIDlet
extends MIDlet
implements CommandListener, MessageListener,Runnable {
  private MMSSender mSender = null;
  private Thread mReceiver = null;
  private Command mExitCommand = new Command("Exit", Command.EXIT, 2);
  private Command mRedCommand = new Command("Send Red", Command.SCREEN, 1);
  private Command mBlueCommand = new Command("Send Blue", Command.SCREEN, 1);
  protected static final String RED_IMAGE = "/red.png";
  protected static final String BLUE_IMAGE = "/blue.png";
  protected static final String DEFAULT_IMAGE = "/wait.png";

  private Display mDisplay = null;
  protected ImageItem mColorSquare = null;
  protected Image mInitialImage = null;
  private String mAppID = "MMSMIDlet";
  private TextField mNumberEntry= null;
  private Form mForm = null;
  private Integer mMonitor = new Integer(0);
  public MMSMIDlet() {
    mSender = MMSSender.getInstance();

  }
```

```
public void commandAction(javax.microedition.lcdui.Command c,
javax.microedition.lcdui.Displayable d) {
  if (c == mExitCommand) {
    if (!mSender.isSending()) {
      destroyApp(true);
      notifyDestroyed();
    }
  } else if (c == mRedCommand) {
    String dest = mNumberEntry.getString();
    if (dest.length() > 0)
      mSender.sendMsg(dest, mAppID, RED_IMAGE);

  } else if (c == mBlueCommand) {
    String dest = mNumberEntry.getString();
    if (dest.length() > 0)
      mSender.sendMsg(dest, mAppID, BLUE_IMAGE);
  }
    }


protected void destroyApp(boolean param) {
  mEndNow = true;
  try {
    conn.close();
  } catch (IOException ex) {
  System.out.println("destroyApp caught: ");
    ex.printStackTrace();

  }
}
protected void pauseApp() {
  mEndNow = true;
  try {
    conn.setMessageListener(null);
    conn.close();
  } catch (IOException ex) {
   System.out.println("pausetApp caught: ");
  ex.printStackTrace();

  }
}
```

```
protected void startApp() {
  if (mForm == null) {
    mForm = new Form(mAppID);
    mNumberEntry = new TextField("Connect to:",
    null, 256, TextField.PHONENUMBER);
    try {
      mInitialImage = Image.createImage(DEFAULT_IMAGE);
    } catch (Exception ex) {
    System.out.println("starttApp caught: ");
     ex.printStackTrace();
    }

    mColorSquare = new ImageItem(null, mInitialImage,ImageItem.
    LAYOUT_DEFAULT, "waiting for image");
    mForm.append(mNumberEntry);
    mForm.append(mColorSquare);
    mForm.addCommand(mExitCommand);
    mForm.addCommand(mRedCommand);
    mForm.addCommand(mBlueCommand);
    mForm.setCommandListener(this);
  }
  Display.getDisplay(this).setCurrent(mForm);

  try {
    conn = (MessageConnection) Connector.open("mms://:" + mAppID);
    conn.setMessageListener(this);
    } catch (Exception e) {
    System.out.println("startApp caught: ");
    e.printStackTrace();
  }
  if (conn != null) {
    startReceive();
  }
}
private boolean mEndNow = false;
private void startReceive() {

  mEndNow = false;
  // Start receive thread
  mReceiver = new Thread(this);
  mReceiver.start();
  }

protected MessageConnection conn = null;
```

```
 protected int mMsgAvail = 0;
 public void run() {
 Message msg = null;
 String msgReceived = null;
 Image receivedImage = null;

   mMsgAvail = 0;

   while (!mEndNow) {
     synchronized(mMonitor) { // Enter monitor
       if (mMsgAvail <= 0)
       try {
        mMonitor.wait();
        } catch (InterruptedException ex) {
      }
       mMsgAvail--;
       }
     try {
     msg = conn.receive();
     if (msg instanceof MultipartMessage) {
    MultipartMessage mpm = (MultipartMessage)msg;
    MessagePart[] parts = mpm.getMessageParts();
    if (parts != null) {
       for (int i = 0; i < parts.length; i++) {
    MessagePart mp = parts[i];
    byte[] ba = mp.getContent();
    receivedImage = Image.createImage(ba, 0, ba.length);
    Display.getDisplay(this).callSerially(
    new SetImage(receivedImage));
       } //of for
    }
     }
     } catch (IOException e) {
     System.out.println("Receive thread caught: ");
     e.printStackTrace();
   }
} // of while
 }
  private void getMessage() {
synchronized(mMonitor) {
    mMsgAvail++;
    mMonitor.notify();
  }
 }
```

```
  public void notifyIncomingMessage(MessageConnection msgConn) {
    if (msgConn == conn)
   getMessage();
      }


  class SetImage implements Runnable {
    private Image img = null;
     public SetImage(Image inImg) {
    img = inImg;
      }
       public void run() {
     mColorSquare.setImage(img);
    }
 }
}
```

The `MessageConnection` is opened in server mode. Unlike SMS, MMS uses an application ID instead of a port to identify the message routing endpoint. Our application ID is stored as `mAppID` and is set to "MMSMIDlet". Once the `MessageConnection` is obtained from `Connector.open()`, `MMSMIDlet` is registered as the `MessageListener` for incoming messages.

The `startReceive()` method starts a receive thread that will pick up and process the incoming MMS messages. Initially, this thread will be blocked, waiting on a monitor called `mMonitor`. This thread will be notified whenever an incoming MMS message arrives, in the `getMessage()` method. In the `run()` method, you can see that `receive()` is used to pick up the pending MMS message. The `MessagePart` that has the image is then extracted, and the image is displayed on the GUI.

Sending MMS Messages with MMSSender

The `MMSSender` class is used by `MMSMIDlet` to send multipart messages. Each outgoing message is sent on a new thread. The source code of the `MMSSender` class is shown in Listing 11-4.

Listing 11-4. *Sending MMS Messages with MMSSender*

```
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.wireless.messaging.*;
import java.io.*;

public class MMSSender implements Runnable {
  private static MMSSender inst = new MMSSender();
  private MMSSender() {
  }
  public static MMSSender getInstance() {
   return inst;
  }
  private String mReceiver = null;
  private String mAppID = null;
```

```
private String mImageToSend = null;
private boolean mSending = false;
public void sendMsg(String rcvr, String appid, String img) {
  if (mSending) return;
  mReceiver = rcvr;
  mAppID= appid;
  mImageToSend = img;
  Thread th = new Thread(this);
  th.start();
}
public boolean isSending() {
  return  mSending;
}
// Send the color image
public void run() {
  mSending = true;
  try {
  sendMMS();
  } catch (Exception ex) {
  }
   mSending = false;
}

public void sendMMS() {
  String address = "mms://" + mReceiver + ":" + mAppID;
  MessageConnection conn = null;
  try {
  /** Open the message connection. */
  conn = (MessageConnection) Connector.open(address);
  MultipartMessage mpMessage = (MultipartMessage) conn.newMessage(
  MessageConnection.MULTIPART_MESSAGE);
  mpMessage.setSubject("MMSMIDlet Image");
  InputStream is = getClass().getResourceAsStream(mImageToSend);
  byte[] bImage = new byte[is.available()];
  is.read(bImage);
  mpMessage.addMessagePart(new MessagePart(bImage, 0, bImage.length,
  "image/png", "id1",
  "location", null));
  conn.send(mpMessage);
  } catch (Throwable t) {
  System.out.println("Send caught: ");
  t.printStackTrace();
  } finally {
```

```
    if (conn != null) {
      try {
      conn.close();
      } catch (IOException ioe) {
    System.out.println("Closing connection caught: ");
       ioe.printStackTrace();
      }
    }
    }
    }
}
```

The basic structure is identical to the earlier SMS `Sender` class. However, the message created here for sending is a `MultipartMesssage`. The subject of the message is set to "MMSMIDlet Image". For the one and only `MessagePart`, the MIME type is "image/png", the content ID is "id1", and the content location is set to "location". The actual content of the message part is the image to be displayed on the destination device. The `MessagePart` is created, populated, and then added to the message. The message is then sent using the `MessageConnector` in the `sendMMS()` method, which is always called on a new thread.

Testing MMS Send and Receive

You can test out the `MMSMIDlet` using one of the following:

- The WMA console utility of WTK 2.x
- Two instances of the `MMSMIDlet`

Using the WMA Console

First, start the emulator running with an instance of the `MMSMIDlet`. From the KToolbar menu, select File ➤ Utilities. In the WMA box, click the Open Console button. This will start a console with its own phone number (address). Click the Send MMS button; a dialog box will be shown for entry of MMS header and message parts. Enter the information listed in Table 11-2 for the header.

Table 11-2. *Information for MMS Testing on WMA Console*

Field	Value
Subject:	MMSMIDlet Image
Application-ID:	MMSMIDlet
To:	mms://+5550000:MMSMIDlet

This "to" address assumes that you are running the WTK in its default configuration. Click the Parts tab, and add a part that includes the `red.png` image. Figure 11-5 shows the console with the message part added.

Figure 11-5. *Sending an MMS message to MMSMIDlet via WMA console*

Click the Send button. Take a look at the `MMSMIDlet` display—it should now show the car image with a red background. Figure 11-5 shows the result.

Using Two Emulator Instances

The second way of testing `MMSMIDlet` is to use two running instances of the emulator. Start one instance, and then the second one. In the "Connect to:" text field, enter the address of the first instance. By default, it will be `+5550000`. Then select `Send Red` from the menu of the second instance. You should see the red image displayed on the first instance.

■ **Tip** The WTK environment is adequate for debugging and testing of standalone MIDP applications. When testing messaging applications using multiple instances, however, it can have quirks. The one and only solution is to make sure you fully test your messaging application on your target device and network before deployment.

Summary

Extending the CLDC's Generic Connection Framework, the Wireless Messaging APIs add the ability for J2ME applications to send and receive SMS messages as well as receive CBS broadcast messages. The latest JSR 205, specifying WMA 2.0, extends this further to take advantage of the content-rich Multimedia Message Service that is becoming available with 2.5G and 3G networks.

CHAPTER 12

Bluetooth and OBEX

Internet on cell phones is all about connecting to things that are a world apart wirelessly. Interestingly enough, frequently you may wish that you could somehow connect to things (devices, machines, or even people) that are right next to you. For example, you may be at a business associate's office, next to a printer that you wish you could use to print an urgent e-mail you've just received; or you may have walked past your dream house, which happens to be up for sale, and you want more information on it right away. While the Internet may help in some situations, it would be wonderful if there were a painless—and ideally airtime free—way for connecting to things that are next to you.

There is!

Bluetooth is a radio connectivity technology designed for creating Personal Area Networks (PANs). It is all about connecting to things that are next to you, wirelessly. Java APIs for Bluetooth is an optional API that adds radio PAN connectivity to MIDP applications.

Other than using radio, some devices can also communicate externally via an infrared beam. This is especially popular on phones that have built-in PDAs. OBEX, or Object Exchange Protocol, is a communication protocol that enables applications to talk to one another easily over infrared (OBEX can actually work over other transport/media as well, such as Bluetooth). The optional OBEX API contains utility classes that simplify programming using the protocol.

Bluetooth, CLDC, and MIDP

The Bluetooth radio hardware operates in the 2.45-gigahertz Industrial, Scientific, and Medical (ISM) frequency band, allowing for unlicensed operation worldwide. Bluetooth networks are formed ad hoc and dynamically, when Bluetooth-enabled devices come into proximity of one another. Technically, a Bluetooth network is a piconet, and it can consist of one master device and up to seven slave devices. The number of devices supported can be expanded beyond eight when a master device on one piconet acts as a slave in another, working as a bridge. However, all these hardware and radio protocol details are transparent to the application developer using the Java API for Bluetooth.

Java API for Bluetooth is not included as part of MIDP. It is also not a mandatory part of JTWI 1.0. Phones that have Bluetooth built in are in the minority, and vendors may expose proprietary APIs instead of the Java API for Bluetooth (or not expose Java API at all). At this time, the API is more prevalent with larger PDAs that support the CDC.

Relying only on CLDC 1.0, Java API for Bluetooth can be readily implemented on any modern devices supporting CLDC, MIDP, and/or JTWI 1.0. It is anticipated that the API will gain better vendor support in the near future.

Figure 12-1 illustrates the relationship between the optional Bluetooth API, CLDC, and MIDP.

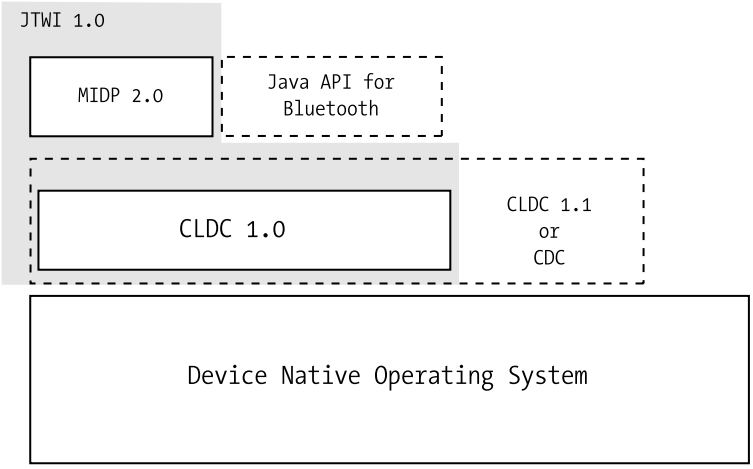


Figure 12-1. *Relationships between Java API for Bluetooth, CLDC, and MIDP*

The Bluetooth API leverages the Generic Connection Framework (GCF) built into CLDC in a similar manner to WMA and File Connection covered in earlier chapters.

JSR 82: The Bluetooth JSR

JSR 82 is called Java API for Bluetooth Wireless Technology, and the specification describes two complete and separate optional APIs:

- Java API for Bluetooth
- Java API for OBEX

While the first API covers exclusively communications via Bluetooth radio technology, the second one focuses on the OBEX protocol. The OBEX protocol can be implemented over a Bluetooth PAN, IP networks, and infrared communications links. You are most likely to find OBEX implemented over infrared links.

The first part of this chapter will focus on the Bluetooth APIs, the latter part on OBEX.

Networking with Devices Near You

Bluetooth is short-ranged radio technology that enables communications for devices physically located close to one another. A Bluetooth implementation contains both hardware and software components (and software in ROM, also known as firmware), as illustrated in Figure 12-2.

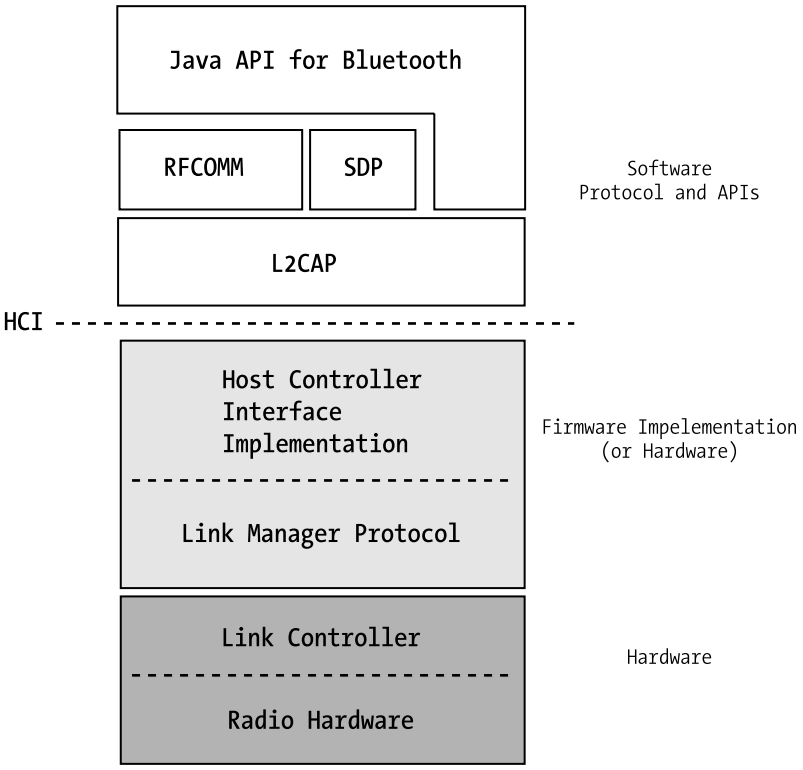


Figure 12-2. *A Bluetooth implementation*

A network consisting of devices connected via Bluetooth is often called a Personal Area Network (or PAN for short). The software portion of a Bluetooth "stack" enables data to be interchanged between locally connected devices in a variety of ways. The different interactions possible between devices in a PAN can be roughly classified as follows:

- *Discovery*: Find out what devices are connected, how they may be useful, and when a device is no longer available (for example, you may have traveled out of range).
- *Client activities*: Use services that other devices provide. For example, use a printer nearby to print your e-mail.
- *Server activities*: Provide services and/or information that other devices may use. For example, a Bluetooth-enabled storage server may accept data from mobile Bluetooth devices.
- *Peer activities*: Act as both client and server within an activity. For example, a business card exchange application may enable two phones to exchange business card information using Bluetooth.

The Bluetooth Service Model

Figure 12-3 illustrates typical interactions between Bluetooth devices.

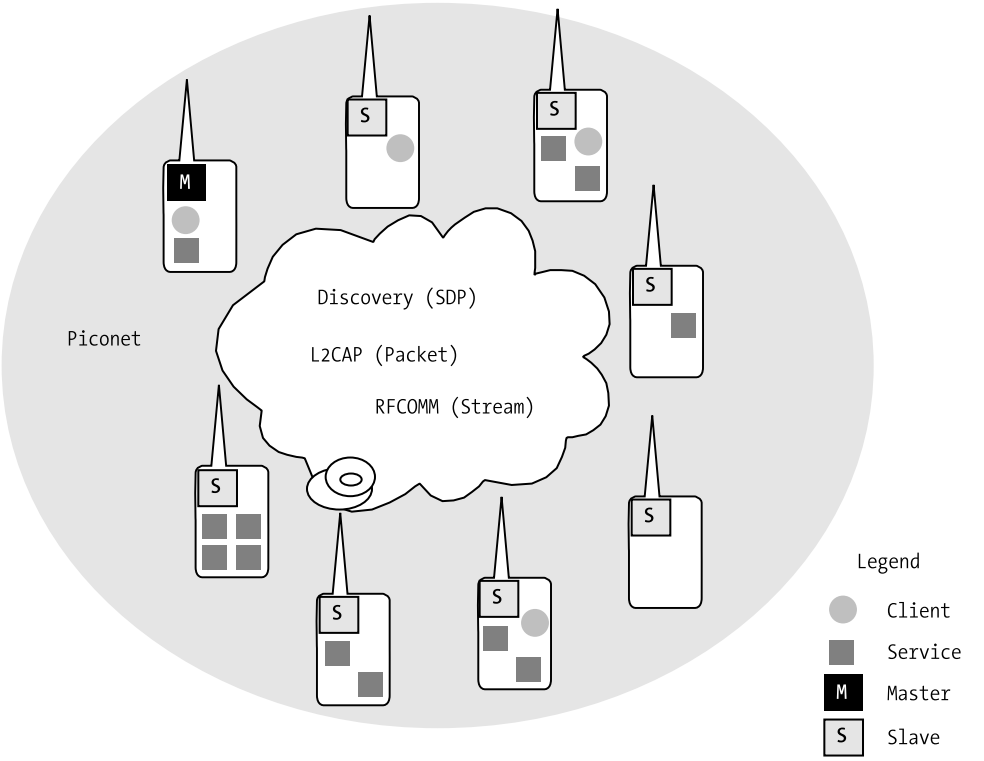


Figure 12-3. *Bluetooth device interactions*

In Figure 12-3, note that a single Bluetooth device can be offering multiple services at the same time. Bluetooth devices can also support both client and server functionality simultaneously. On a hardware level, a single master Bluetooth device can synchronize up to seven slave devices in a Bluetooth piconet.

Devices are the discoverable entities in a Bluetooth network. The discovery process is called an inquiry in Bluetooth lingo. You need to perform an inquiry to discover devices in your PAN before finding out what services the devices are offering.

Each service in a Bluetooth network is uniquely identified by a UUID. Any particular device in the Bluetooth network can be offering zero or more services. The same service may be offered by more than one device in the network. For example, one can easily imagine a printing service offered by a number of printers in the same room.

■ **Note** A UUID is a Universally Unique identifier. This is usually a very large number, typically 128 bits. UUIDs are generated using a combination of unique items (such as the MAC address on an ethernet interface) and random elements (the clock ticks on the computer at time of number generation). The idea is that the probability of two numbers generated, anywhere in the world, at any time, is infinitesimally small. In Bluetooth, some UUIDs are "short" and are only 16 or 32 bits long. However, these short UUIDs are always converted to 128 bits before comparison. 128-bit UUIDs are frequently expressed in programs as hexidecimal strings ("BAE0D0C0B0A0009555706050403020l0", for example).

The Bluetooth specification describes a number of interoperability profiles, much like the role of the profiles in J2ME, for implementers of Bluetooth devices. These profiles specify interoperability standards between different implementations. The Service Application Discovery Profile (SADP) enables applications running on Bluetooth devices to discover services. The Java API for Bluetooth works over this profile to give you the high-level ability to discover services (with or without having to explicitly discover the devices).

At the lower level, the actual protocol used for service discovery between devices is called the Service Discovery Protocol (SDP).

Other than the SADP, JSR 82–compliant devices must also support the Generic Access Profile, or GAP (for access to device remotely), and the Serial Port Profile, or SPP (serial port emulation for sending and receiving streamed data between devices).

The Bluetooth API

The Java API for Bluetooth is delivered as the `javax.bluetooth` package. The following sections describe the most important classes and interfaces in this package.

Accessing Local Bluetooth Stack

You can talk to the software stack local to your device using the `LocalDevice` class. For example, you can get information on your stack by calling one of the following:

```
String getBluetoothAddress() ;
DeviceClass getDeviceClass();
DiscoveryAgent getDiscoveryAgent();
String getFriendlyName() ;
```

The first method returns the address, specific to Bluetooth, for the device. You don't really need to know how the address is formatted, since you will either store it or send it to somebody else "as is."

`getDeviceClass()` will return the major class of the device. `getDiscoverable()` will indicate whether the device can be discovered by other devices. The `getDiscoveryAgent()` method is a static factory method that can be used to obtain the singleton instance of the device's

`DiscoveryAgent` (covered in the next section, "Discovering Devices"). `getFriendlyName()` will return a string that contains a human readable (and understandable) name for your device.

You can determine if your device is discoverable by other Bluetooth devices with a call to the following:

```
int getDiscoverable() ;
```

To make your device discoverable, or disable its visibility in the network, call

```
boolean setDiscoverable(int mode)
```

Before you can call any of the information methods, you will need an instance of a `LocalDevice`. This singleton instance is often called the local Bluetooth manager. It can be obtained using this factory method:

```
static LocalDevice getLocalDevice() ;
```

To obtain the singleton instance of your local Bluetooth manager, use code similar to the following:

```
LocalDevice myDevice = LocalDevice.getLocalDevice();
```

Each Bluetooth software stack must have a set of properties that you can query; use this static method on the `LocalDevice`:

```
static String getProperty(String property) ;
```

Table 12-1 shows some properties for which you can query.

Table 12-1. *Properties That Must Be Available on a Bluetooth Device*

Property	Description
`bluetooth.api.version`	API version supported. Currently "1.0".
`bluetooth.master.switch`	Indicates whether a switch between master and slave Bluetooth role is allowed on this device. Not all devices support role switching between master and slave.
`bluetooth.sd.attr.retrievable.max`	The maximum number of service record attributes that can be retrieved. Service records and attributes are described later in this chapter.
`bluetooth.connected.devices.max`	The maximum number of connected devices in this implementation. Bluetooth supports the concept of a "parked connection," which can increase the maximum number of connected devices.
`bluetooth.l2cap.receiveMTU.max`	The maximum transmission unit size in bytes supported in the L2CAP low-level protocol. The L2CAP protocol is described later in this chapter.
`bluetooth.sd.trans.max`	The maximum number of concurrent service discovery transactions allowed.

Discovering Devices

The Bluetooth API has the concept of a discovery agent. You can think of it as a helper process that assists you in the discovery of other devices or services in a PAN.

It is called an agent because it works independently. Once you tell it what to do, it goes about its task merrily on your behalf. Sometime later, you can come back to the agent and request the status. Or you can tell the agent to call you back when it makes a new discovery.

To get an instance of a `DiscoveryAgent`, you need to go through the Bluetooth manager (the `LocalDevice` class). Basically, you need to make a call similar to the following:

```
DiscoveryAgent myDa = LocalDevice.getInstance().getDiscoveryAgent();
```

You can perform discovery on a device level or a service level. Device-level discovery allows for more control over the discovery process, but requires significantly more complex coding. When you perform discovery on a service level, the `DiscoveryAgent` handles the device-level manipulations for you.

Starting and Stopping Device Discovery

When you have a `DiscoveryAgent` instance, you can tell it explicitly to start discovery for devices via this method:

```
boolean startInquiry(int accessCode, DiscoveryListener listener) ;
```

The access code determines the type of inquiry and can be either `DiscoveryAgent.GIAC` (General Inquiry Access Code) or `DiscoveryAgent.LIAC` (Limited Inquiry Access Code). These codes are specified by the Bluetooth "Assigned Numbers" document (see `http://www.bluetooth.org/assigned-numbers/`). Almost all Bluetooth devices you encounter can be discovered using `GIAC`.

`startInquiry()` will start device discovery. For each device that is discovered, the listener that you register will receive a notification. This listener must implement the `DiscoveryListener` interface. The interface has four methods, but only two are important for device discovery:

```
void deviceDiscovered(RemoteDevice btDevice, DeviceClass cod) ;
void inquiryCompleted(int discType) ;
```

The `deviceDiscovered()` notification method is called when a device is discovered during the inquiry. The `inquiryCompleted()` method is called when the inquiry process is completed. This can be due to a timeout period (determined by the Bluetooth implementation) or when the `DiscoveryAgent` is being told to stop the discovery.

The `inquiryCompleted()` notification method is called when the discovery process completes. A `discType` value of `DiscoveryListener.INQUIRY_COMPLETED` indicates a normal completion, while a `DiscoveryListener.INQUIRY_TERMINATED` indicates a manual termination. Error-caused termination will have a `discType` value of `DiscoveryListener.INQUIRY_ERROR`.

You can tell the `DiscoveryAgent` to stop the discovery, before its natural termination, by calling its `cancelInquiry()` method:

```
public boolean cancelInquiry(DiscoveryListener listener);
```

Note that you must supply the same listener as the one that you've called `startInquiry()` with; otherwise, the discovery will not be stopped, and the method returns false.

A Simpler Way to Discover Devices

The DiscoveryListener callbacks are performed on a system notification thread, and the methods should complete their work as soon as possible. Any work that takes significant time should be performed on another thread. This requirement often makes device discovery code difficult to write and debug. An additional method on DiscoveryAgent can simplify discovery by eliminating the need to work with callback:

```
public RemoteDevice[] retrieveDevices(int option);
```

option can be either DiscoveryListener.CACHED or DiscoveryListener.PREKNOWN. This method will not start discovery; however, it will return RemoteDevices cached (discovered from a previous inquiry) or preknown. Preknown devices are Bluetooth devices that you can typically configure using a utility (called the Bluetooth Control Center, covered later) on your device.

Using code similar to the following, you can discover a list of nearby devices using relatively simple code:

```
myDiscoveryAgent.startInquiry(DiscoveryAgent.GIAC, myDoNothingListener);
Thread.sleep(10000l);
mDiscoveryAgent.cancelInquiry(myDoNothingListener);
RemoteDevice  [] remoteDevices = myDiscoveryAgent.retrieveDevices(CACHED);
```

The preceding code basically performs an explicit inquiry, waits 10 seconds (a reasonable delay for discovery), and then terminates it. After termination of inquiry, the retrieveDevices() method is used to obtain the discovered devices. The myDoNothingListener instance passed into startInquiry() implements DiscoveryListener, but does nothing within the four methods.

■ **Caution** There is a slight risk, when using the preceding simple code, that the discovery process will not have yet completed after the 10 second delay. To be absolutely sure, you need to use the listener-based callback, shown next. Another solution is to let the user set/modify the delay via a MIDlet property.

Discovering Services

Once you have a RemoteDevice, you can search through the services that it supports. You can use the searchServices() method on the DiscoveryAgent for this purpose:

```
public int searchServices(int[] attrSet,  UUID[] uuidSet,
         RemoteDevice btDev, DiscoveryListener discListener)
         throws BluetoothStateException
```

You specify the RemoteDevice via btDev. The uuidSet contains one UUID for each service you are interested in discovering. The attrSet contains the service record attributes you want to obtain with the search. discListener is a DiscoveryListener that you implement. You should save the returned transaction ID for the search. Your registered DiscoveryListener will be called with the results and this transaction ID. This transaction ID allows you to perform concurrent searches on multiple remote devices. Here are the two methods on DiscoveryListener that are used for service discovery callback:

```
void servicesDiscovered(int transID, ServiceRecord[] servRecord) ;
void serviceSearchCompleted(int transID, int respCode) ;
```

`servicesDiscovered()` is called when services are found during a search. The `transID` gives the transaction ID, while the `servRecord` array contains an entry for each matching service. `serviceSearchCompleted()` is called when the search is ending, either because of successful completion, forced termination, or error. You can terminate a search by calling the `DiscoveryAgent` method:

```
public boolean cancelServiceSearch(int transID);
```

A Simpler Way to Discover Services

Combining device discovery with service search, the pseudo-code to discover a Bluetooth service, given its UUID, may be as follows:

```
obtain the DiscoveryAgent
tell DiscoveryAgent to startInquiry()
save every discovered RemoteDevice discovered in a Vector
wait until device discovery finishes or terminate inquiry with cancelInquiry()
for each RemoteDevice discovered {
    tell DiscoveryAgent to searchServices() specifying the UUID seeked
    save every service record returned
   }
```

The preceding pseudo-code translates to a lot of Java code. Because the discovery process is centered around asynchronous listener callbacks, the code will also necessarily involve multiple concurrent threads and tricky synchronization.

Unfortunately, no other way exists if you require fine control over service selection between devices. If you don't really care which device a service comes from, however, there is a simpler way to perform service discovery. The `selectService()` method on `DiscoveryAgent` can be used to find a service when you don't care which device it may come from:

```
String selectService(UUID uuid, int security, boolean master);
```

The returned value, if not null, is a connection string that you can use with GCF's `Connector.open()` to start talking to the service. `security` indicates whether authentication and encryption should be used; `security` can be one of the following:

- `ServiceRecord.NOAUTHENTICATE_NOENCRYPT`
- `ServiceRecord.AUTHENTICATE_NOENCRYPT`
- `ServiceRecord.AUTHENTICATE_ENCRYPT`

Bluetooth authentication, if implemented, is based on a PIN-generated challenge/response sequence. Encryption also requires this PIN; therefore it is not possible to perform encryption without first authenticating. Note that authentication and encryption may not be implemented by all Bluetooth implementations. The master flag indicates whether the client must be a master in the underlying Bluetooth connection.

When using the `selectService()` method, the code to obtain a connection to a desired service given its UUID is reduced to two lines:

```
  String  dateConnect = mDiscoveryAgent.selectService(DATING_SERVICE_ID,
                ServiceRecord.NOAUTHENTICATE_NOENCRYPT, false);
 StreamConnection  conn = (StreamConnection) Connector.open(dateConnect);
```

Access to Remote Devices

The previous section shows how to search for services on a `RemoteDevice`. If you are working with Bluetooth at a device level, the `RemoteDevice` instance also has security methods to authenticate and encrypt a connection:

```
boolean authenticate();
boolean authorize(Connection conn) ;
boolean encrypt(Connection conn, boolean on);
```

And a set of methods to test the security status of the connection:

```
boolean isAuthenticated() ;
boolean isAuthorized(javax.microedition.io.Connection conn) ;
boolean isEncrypted() ;
boolean isTrustedDevice();
```

■ **Note** When you create a server-side notifier using the GCF (shown later in the section entitled "Creating a Bluetooth Service"), you can specify an attribute on the connect string that indicates whether the service requires authentication, authorization, or encryption. If used, authentication must always be performed first before encryption or authorization.

The Bluetooth address and the user-understandable name of the device can be obtained via the following:

```
String getBluetoothAddress() ;
String getFriendlyName(boolean alwaysAsk) ;
```

If you have a GCF connection opened to a service, and you want to get the corresponding remote device, there is a static method that you can use:

```
static RemoteDevice getRemoteDevice(Connection conn) ;
```

The Bluetooth Control Center

The Bluetooth Control Center (BCC) is an external utility (not part of the API) that must exist in every JSR 82–compliant implementation. BCC allows the user to perform explicit configuration on the local Bluetooth stack. Some of the configuration that you may be able to specify include the following:

- The set of `preknown` Bluetooth devices (for example, printers that you know about)
- The text-based name used for your device during discovery
- The PIN for authentication and encryption
- The timeout period for device discovery
- Default security settings
- Turning on or off the discoverability of the device
- Turning the radio hardware on or off, essentially enabling and disabling Bluetooth

The exact user interface and configurability of a BCC is dependent on the implementation.

Within the Wireless Toolkit 2.x, you can access the BCC via the KToolbar menu by selecting Edit ➤ Preferences and then clicking the Bluetooth/OBEX tab.

ServiceRecord and Service Attributes

A `ServiceRecord` is an entry in the Service Discovery Database (SDDB), used by Bluetooth during service discovery. This database is maintained by the Bluetooth manager on each device. This is the database that will be searched when a client searches a `RemoteDevice` for service matches. Underneath the hood, transparent to the API, service discovery is performed via the Service Discovery Protocol.

The `ServiceRecord` entry is just a set of attributes. Each attributes has an ID and a value. The ID is a 16-bit unsigned integer. The value can be various data types and is represented in Java by a `DataElement` instance. Some frequently used attribute IDs are listed in Table 12-2.

Table 12-2. *Common ServiceRecord Attribute IDs*

ID	Description
`0x0000`	`ServiceRecordHandle`
`0x0001`	`ServiceClassIDList`
`0x0002`	`ServiceRecordState`
`0x0003`	`ServiceID`
`0x0004`	`ProtocolDescriptorList`

In Table 12-2, you can see that the UUID of the service corresponds to ServiceRecord attribute ID 0x0003. There are a very large number of possible attributes. For the entire list of attributes, their descriptions, and data types, see the Bluetooth "Assigned Numbers" document (http://www.bluetooth.org/assigned-numbers/sdp.htm).

Incidentally, the list of attributes in Table 12-2 is exactly the mandatory attributes that every ServiceRecord must have. They are also the default attributes that will be fetched during service discovery via a searchServices() method call.

The ServiceRecord class has the following methods for manipulation of attributes:

```
int[] getAttributeIDs(); .
DataElement getAttributeValue(int attrID);
boolean setAttributeValue(int attrID, DataElement attrValue);
```

The getAttributeIDs() method returns all the attributes that can be obtained via the getAttributeValue() call. Not all possible attributes are available; availability depends on the set of attributes specified during service discovery. If you want to update a ServiceRecord, use setAttributeValue(). You must call updateRecord() on the LocalDevice instance for the change to be reflected in the SDDB. See the next section for a description of how to place a ServiceRecord into the SDDB in the first place.

The GCF connection string associated with a ServiceRecord (that is, an available service) can be obtained via a call to the getConnectionURL() method:

```
String getConnectionURL(int requiredSecurity, boolean mustBeMaster);
```

If the ServiceRecord is result of discovery, you can also obtain a reference to the RemoteDevice by calling this method:

```
RemoteDevice getHostDevice();
```

Creating a Bluetooth Service

To offer a service over Bluetooth, your application first needs to register a ServiceRecord in the SDDB. The way you create and register a ServiceRecord is coupled with the GCF. First, you need to create a StreamConnectionNotifier (similar to a ServerSocketConnection). For example, the following call to Connector.open() will create a StreamConnectionNotifier and the corresponding ServiceRecord.

```
StreamConnectionNotifier myNotifier = (StreamConnectionNotifier)
Connector.open("btspp://localhost: BAE0D0C0B0A000955570605040302010;name=Dating
Service;authorize=false"
);
```

The protocol specification for the GCF connection string is "btspp://" for the Bluetooth Serial Port Profile. This is a Bluetooth profile that all JSR 82–compliant devices must implement, and it provides RS232 serial port emulation. Underneath the hood, a high-level stream-based protocol called RFCOMM is working on top of a lower-level packet-based protocol called L2CAP.

■ **Note** The Java API for Bluetooth also adds `L2CAPConnection` and `L2CAPConnectionNotifier` for working with the lower-level L2CAP protocol directly. Working with the lower-level L2CAP protocol is significantly more difficult because you must work with packet size limit, handle fragmentation, and reassembly of large messages yourself. L2CAP is often used directly by native applications that perform audio/video streaming. `L2CAPConnection` uses the protocol specification "btl2cap://" in the GCF connection string. The RFCOMM higher-level protocol simplifies application programming by providing a stream-based API and handling the packet assembly details for you.

Instead of a port number, as in IP-based connections, the UUID of the service is specified after the hostname, separated by a colon (:). A set of comma-separated connection parameters can follow the UUID in the GCF connection string. Some more useful parameters include `authenticate`, `encrypt`, `authorize`, and `master`.

You can obtain the `ServiceRecord`, if you have a notifier created by `Connector.open()`, using a method on the `LocalDevice`:

```
ServiceRecord getRecord(Connection notifier);
```

To register the `ServiceRecord` with the SDDB and wait for incoming connections, call the blocking `acceptAndOpen()` method on the `StreamConnectionNotifier`.

```
StreamConnection conn = myNotifier.acceptAndOpen();
```

You can update the registered `ServiceRecord` in the SDDB using the `LocalDevice` method:

```
void updateRecord(ServiceRecord srvRecord);
```

The `ServiceRecord` for a service is removed from the SDDB when the `StreamConnectionNotifier` is closed.

A Bluetooth Dating Service

The first example MIDlet creates a simple Bluetooth "dating service." It is odd how sometimes people in the same room who are attracted to each other are reluctant to start talking and "break the ice." This MIDlet may help.

You tell the MIDlet the type of date you're looking for, and the MIDlet will use Bluetooth to query anybody who comes near you for compatibility. Once compatibility is established, your potential date's e-mail address is displayed on your phone.

The MIDlet is called `BTMIDlet`. Create a new project called BTMIDlet and copy the two source files into the `src` directory of the WTK. Build the project.

Setting Your Dating Preferences

Next, you need to set five MIDlet properties using KToolbar: click the Settings button, click the User Defined tab, and add the MIDlet properties in Table 12-3.

Table 12-3. *MIDlet Properties for BTMIDlet Project*

Key	Value
BTMIDlet-mycontact	tallguy@yahoo.com
BTMIDlet-myheight	tall
BTMIDlet-mypref	male
BTMIDlet-seekheight	short
BTMIDlet-seekpref	female

To keep things simple, this example assumes you're a tall male, looking for a short female.

To test this MIDlet, you will need to start two instances of the emulator. The second instance must emulate the subject of your dating interest. To make this happen, create a new project called BT2, with the MIDlet name `BTMIDlet`. Copy the two source files into the `src` directory of the new BT2 project. Build the project. Next, enter the MIDlet properties in Table 12-4 for this project.

Table 12-4. *MIDlet Properties for BT2 Project*

Key	Value
BTMIDlet-mycontact	shortgal@yahoo.com
BTMIDlet-myheight	short
BTMIDlet-mypref	female
BTMIDlet-seekheight	tall
BTMIDlet-seekpref	male

Finally, run an instance of BT2. Without starting another KToolbar, open the BTMIDlet project, and run an instance of `BTMIDlet`. Now, launch both MIDlets. On initial startup, the security manager will ask for your permission to use Bluetooth. You need to approve it. Shortly after starting, you will see that the owners of the two devices have found each other, as shown in Figure 12-4.

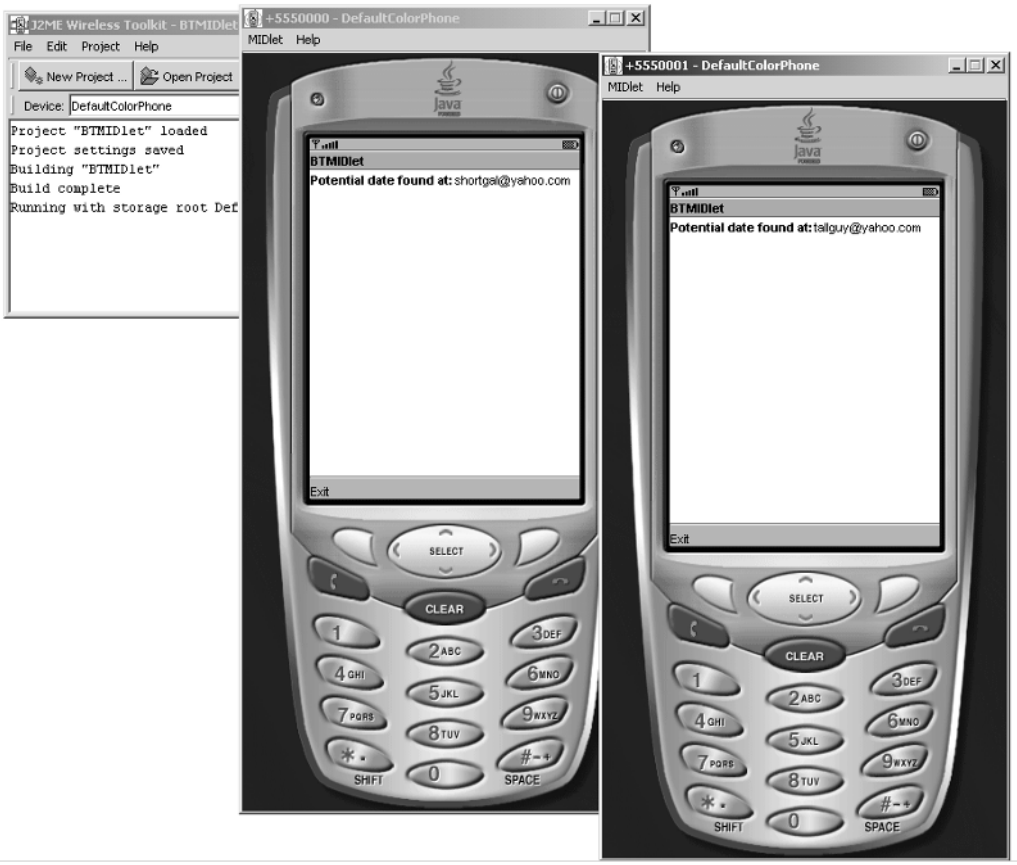


Figure 12-4. *Bluetooth dating service running on WTK emulators*

You may want to start additional instances of BTMIDlet and BT2 to see how the MIDlet behaves in a group situation.

Coding the Bluetooth Client

The `DateClient` class contains the code for the Bluetooth client (see Listing 12-1). This client connects to nearby dating service(s) and writes its own height, sex, and e-mail. This is a singleton instance, obtained via the static `getInstance()` method. The `startClient()` method starts a thread and runs the client. The `stopClient()` method terminates the client thread gracefully. The `setMyInfo()` method is used to set the information that will be written to nearby dating service(s).

Listing 12-1. *Bluetooth Dating Client Code—DateClient.java*

```
import java.io.*;
import javax.microedition.io.*;
import javax.bluetooth.*;

public final class DateClient implements Runnable {
    private Thread mClientThread = null;
    private static DateClient inst = new DateClient();
    private  DateClient() {
    }
    public static DateClient getInstance() {
        return inst;
    }
    private boolean mEndNow = false;

    private static final UUID DATING_SERVICE_ID =
        new UUID("BAE0D0C0B0A000955570605040302010", false);
    private String mDateConnect = null;
    private DiscoveryAgent mDiscoveryAgent = null;

    private String mPref = null;
    private String mHeight = null;
    private String mContact = null;

    public void setMyInfo(String inPref, String inHeight, String inContact) {
        mPref = inPref;
        mHeight = inHeight;
        mContact = inContact;
    }
    public void startClient() {
        if (mClientThread != null)
            return;
        mEndNow = false;
        // Start receive thread
        mClientThread = new Thread(this);
        mClientThread.start();
    }
    public void stopClient() {
        mEndNow = true;
        try {
            mClientThread.join();
        } catch (Exception ex) {}
        mClientThread = null;
    }
```

```
    public void run() {
        // This is the BT client portion of the dating service
        try {
            mDiscoveryAgent = LocalDevice.getLocalDevice().getDiscoveryAgent();
        } catch (Exception ex) {
        }

        StreamConnection conn  = null;
        DataOutputStream dos  = null;
        while( !mEndNow)  {
            try  {
                 mDateConnect = mDiscoveryAgent.selectService(DATING_SERVICE_ID,
                ServiceRecord.NOAUTHENTICATE_NOENCRYPT, false);

                if (mDateConnect != null)  {
                    conn = (StreamConnection) Connector.open(mDateConnect);
                    dos = conn.openDataOutputStream();
                    dos.writeUTF(mPref);
                    dos.writeUTF(mHeight);
                    dos.writeUTF(mContact);
                    dos.flush();
                    dos.close();
                }

            } catch (Exception ex) {
            }
        }
    }

}
```

In Listing 12-1, in the `run()` method, note the use of the `selectService()` method of `DiscoveryAgent` to greatly simplify Bluetooth client coding. This client will discover and use the dating service identified by the `DATING_SERVICE_ID`, a UUID. If there are multiple nearby dating services, however, the Bluetooth implementation will have control over the actual service that will be used.

Coding the Bluetooth Service

The `BTMIDlet.java` file contains both the GUI and the dating service code. The logic for the Bluetooth service is in the `run()` method. A thread called `mServer` is started in the `startApp()` method of the MIDlet for running the service. Listing 12-2 contains the code.

Listing 12-2. *Bluetooth Dating Service—BTMIDlet.java*

```
import java.io.*;
import javax.microedition.midlet.*;
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.bluetooth.*;

import java.io.IOException;

public class BTMIDlet
extends MIDlet
implements CommandListener, Runnable {
    private DateClient mClient = null;
    private Thread mServer = null;

    private Command mExitCommand  = new Command("Exit", Command.EXIT, 2);

    private Display mDisplay = null;
    private StringItem mDateContact = null;
    private Form mForm = null;
    private boolean mEndNow = false;

    private String mLastContact = "";
    private LocalDevice mLocalBT;
    private StreamConnectionNotifier mServerNotifier;
    private static final UUID DATING_SERVICE_ID =
    new UUID("BAE0D0C0B0A0009555706050403020100", false);


    private String myPref = null;
    private String myHeight = null;
    private String myContact = null;

    private String seekPref = null;
    private String seekHeight = null;
    private String seekContact = null;

    public BTMIDlet() {
        mClient = DateClient.getInstance();
        myPref = getAppProperty("BTMIDlet-mypref");
        myHeight = getAppProperty("BTMIDlet-myheight");
        myContact = getAppProperty("BTMIDlet-mycontact");
        seekPref = getAppProperty("BTMIDlet-seekpref");
        seekHeight = getAppProperty("BTMIDlet-seekheight");

    }
```

```
public void commandAction(javax.microedition.lcdui.Command c,
javax.microedition.lcdui.Displayable d) {
    if (c == mExitCommand) {
        destroyApp(true);
        notifyDestroyed();

    }
}


protected void destroyApp(boolean param) {
    mEndNow = true;

    // Finalize notifier work
    if (mServerNotifier != null) {
        try {
            mServerNotifier.close();
        } catch (IOException e) {} // ignore
    }

    // Wait until acceptor thread is done
    try {
        mServer.join();
    } catch (InterruptedException e) {} // Ignore
    try {
        mClient.stopClient();
    } catch (Exception e) {} // Ignore
}

protected void pauseApp() {
}

protected void startApp() {
    if (mForm == null) {
        mForm = new Form("BTMIDlet");
        mDateContact = new StringItem("Potential date found at:",null);
        mForm.append(mDateContact);
        mForm.addCommand(mExitCommand);
        mForm.setCommandListener(this);
    }
    mDisplay = Display.getDisplay(this);
    mDisplay.setCurrent(mForm);
    mEndNow = false;
    startServer();
    mClient.setMyInfo(myPref, myHeight, myContact);
    mClient.startClient();
}
```

```
    private void startServer() {
        if (mServer != null)
            return;
        // Start receive thread
        mServer = new Thread(this);
        mServer.start();

    }

    public void run() {




        try {
            // Get local BT manager
            mLocalBT = LocalDevice.getLocalDevice();

            // Set we are discoverable
            mLocalBT.setDiscoverable(DiscoveryAgent.GIAC);
            String url = "btspp://localhost:" + DATING_SERVICE_ID.toString() +
            ";name=Dating Service;authorize=false";

            // Create notifier now
            mServerNotifier = (StreamConnectionNotifier) Connector.open(
            url.toString());
        } catch (Exception e) {
            System.err.println("Can't initialize bluetooth: " + e);
        }
        StreamConnection conn = null;
        while (!mEndNow) {
            conn = null;
            try {
                conn = mServerNotifier.acceptAndOpen();
            } catch (IOException e) {
                continue;
            }

            if (conn != null)
                processRequest(conn);
        }

    }
```

```
private void processRequest(StreamConnection conn) {
    DataInputStream dis = null;
    String pref = null;
    String height = null;
    String contact = null;
    try {
        dis = conn.openDataInputStream();
        pref = dis.readUTF();
        height = dis.readUTF( );
        contact = dis.readUTF();
        dis.close();
        conn.close();

    } catch (IOException e) {} // Ignore
    if (!mLastContact.equals(contact)) {
        mLastContact = contact;
        if (pref.equals(seekPref)  && height.equals(seekHeight))
            mDisplay.callSerially(new ShowCandidate(contact));
    }
}
class ShowCandidate implements Runnable {
    Display disp = null;
    String contact = null;
    public ShowCandidate(String cont) {
        contact = cont;
    }
    public void run() {
        mDateContact.setText(contact );
    }
}
}
```

In the server code (the `run()` method), the `LocalDevice` is first set to discoverable, then a `StreamConnectionNotifier` is created called `mServerNotifier`. The server thread then waits for incoming requests by calling `acceptAndOpen()`. The incoming connection is read for the sex, height, and e-mail address of the nearby dating candidate. If the items match those you are looking for, the GUI will be updated with the date's e-mail address.

Infrared Communications and OBEX

Unlike the Bluetooth radio-based technology, communications via infrared requires a line-of-sight connection between the senders and receivers. This is because infrared devices communicate via light beams that must be aimed (roughly) at one another. Similar to Bluetooth devices,

however, infrared devices can discover one another when they are in range. Connections between infrared devices can be formed dynamically.

As with Bluetooth, low-level communications over infrared is packet based. With Bluetooth, the "btspp://" protocol provides a high-level stream interface, via the RFCOMM protocol, over the low-level L2CAP packet-based protocol. With infrared communications, the lower-level packet-based protocol is called the IrDA protocol, and OBEX serves as a means to provide a high-level object-based communications protocol on top of IrDA.

OBEX

OBEX, or Object Exchange, is a protocol designed to enable exchange of data such as contact and scheduling information in vCalendar and vCard formats. It is a request/response protocol, loosely modeled after the ubiquitous Hypertext Transfer Protocol (HTTP). OBEX is not exclusively tied to IrDA as its transport protocol. For example, OBEX can work over TCP/IP as well as RFCOMM (Bluetooth).

■ **Tip** While OBEX over TCP/IP and OBEX over RFCOMM/Bluetooth represent possible stackings of software protocols, you are less likely to find many devices supporting them. This is because IrDA and OBEX have a very strong bond if you are creating firmware and/or new devices. Furthermore, Bluetooth and IP networks have high-level protocol solutions that are similar to OBEX, rendering it significantly less important outside of the infrared arena. If you want to experiment, the Wireless Technology Kit 2.x supports these stacks on the emulator.

OBEX Requests

All of the Java APIs for OBEX are in the `javax.obex` package. JSR 82 fully specifies the content of this package.

As a request/response protocol, an OBEX session consists of a series of client requests and the corresponding server responses. Like HTTP, each request and response can contain a set of headers and a body. The `ClientSession` interface in the OBEX API has methods that facilitate the sending of client requests. The available OBEX requests, and their corresponding methods in `ClientSession`, are tabulated in Table 12-5. The `GET` and `PUT` operations, spanning multiple requests, are most frequently used to transfer large binary objects from and to the server.

When you're in a session (when `connect()` returns successful), you can get the current connection ID using the following:

```
public long getConnectionID();
```

Depending on your application's requirement, there are at least two ways to communicate using the OBEX APIs:

- Via OBEX request headers
- Via the `Operation` object with a `PUT` or `GET`

Table 12-5. *OBEX Requests*

OBEX Request	API Method	Description
CONNECT	`HeaderSet connect(HeaderSet hdrs);`	Connects and creates a session with the OBEX server. Must be called successfully before sending other requests. Returns a `HeaderSet`. Uses `getResponseCode()` on the `HeaderSet` to retrieve the server return code.
PUT	`Operation put(HeaderSet hdrs);`	Starts an `OBEX PUT` operation. Returns an `Operation` object. Use this to obtain an output stream that can be used to send arbitrarily large objects.
GET	`Operation get(HeaderSet hdrs);`	Starts an `OBEX GET` operation. Returns an `Operation` object. Use this to obtain an input stream that can be used to receive arbitrarily large objects.
DELETE	`HeaderSet delete(HeaderSet hdrs);`	Performs an OBEX DELETE request, typically used to delete an object on the server.
SETPATH	`HeaderSet setpath(HeaderSet hdrs, boolean backup, boolean create);`	Instructs the server to change working directory via an `OBEX SETPATH` request. `backup` indicates whether the server changes directory up one level before setting the path. `create` indicates whether the directory should be created if it does not yet exists. Returns a `HeaderSet`.
DISCONNECT	`HeaderSet disconnect(HeaderSet hdrs);`	Disconnects from the current session using an `OBEX DISCONNECT` request. Returns a `HeaderSet`.

Communications Using Headers

Other than standard OBEX headers that are predefined in the Javadocs of the `javax.obex.HeaderSet` interface (part of JSR 82), you can also create user-defined headers.

User-defined headers must have a header identifier value between `48` and `255`. In fact, OBEX mandates that headers with a certain identifier must be of a certain type. Table 12-6 shows the range and corresponding type.

Table 12-6. *OBEX User-Defined Header Types*

Identifier Value	Java Type	Actual OBEX Type
48–63	`String`	Unicode string
112–127	`byte[]`	Byte sequence
176–191	`Byte`	Single 8-bit byte
240–255	`Long` (0 to 2^{32}–1 only)	32-bits unsigned integer

Use the HeaderSet interface to set and get the values of user-defined headers. To add a user-defined header to a HeaderSet, use this method:

```
void setHeader(int headerID, java.lang.Object headerValue);
```

Check Table 12-6 to determine an identifier to use and the corresponding header type. For example, to add a user-defined string-typed header to a HeaderSet called OutHeader, use this:

```
String seekHeight = "tall";
OutHeader.setHeader(48, seekHeight);
```

From Table 12-6, you can see that the identifier value of 48 contains a user-defined header of Unicode string type.

To obtain the value of a particular header, use this method:

```
Object getHeader(int headerID);
```

For example, to retrieve the string-valued header set earlier using setHeader(), from a HeaderSet called InHeader, you can use

```
String seekHeight =  (String)  InHeader.getHeader(48);
```

You can get an array of int containing the identifiers of all the headers in a HeaderSet with this method:

```
int[] getHeaderList()
```

The array returned by getHeaderList() will only contain headers that have values set; you can call getHeader() on any of the returned indexes safely.

Every request that returns a HeaderSet has a response code from the OBEX server. However, since a Java method cannot return multiple values of different types, you must make an additional API call on the returned HeaderSet to obtain the OBEX response code for the request:

```
int getResponseCode();
```

To interpret the response code from an OBEX server, consult the documentation for the ResponseCodes class. This class defines the static constants for all the possible OBEX response codes. Table 12-7 shows some of the most frequently used ones, and those used in the upcoming example.

Table 12-7 OBEX *Response Codes (Partial)*

Value	Description
ResponseCodes.OBEX_HTTP_OK	Successful request or operations
ResponseCodes.OBEX_HTTP_VERSION	Version of OBEX_HTTP not supported
ResponseCodes.OBEX_HTTP_UNAUTHORIZED	Unauthorized connection
ResponseCodes.OBEX_HTTP_FORBIDDEN	Forbidden access

The fact that OBEX is a request/response protocol modeled after HTTP is quite evident from Table 12-7.

Communications Using PUT or GET

User-defined headers are sufficient for communication tasks that are based on exchange of small messages. For communications that involve custom data types or large binary objects (files, images, etc.), you can use the `PUT` and `GET` requests. The `put()` method on `ClientSession` can be used to initiate a `PUT` request.

```
Operation put(HeaderSet headers) ;
```

Note that you can still include a `HeaderSet` for the request. For example, you may want to let the server application know the length and data type of the object that you will be sending—and you can set the appropriate headers.

To obtain a large data object from a server, use the `get()` method on `ClientSession`:

```
Operation get(HeaderSet headers);
```

Again, you can set the header of the request. Note that the headers from the response of the server are not directly accessible. Instead, you can use the following methods to obtain some pertinent header information (if they are set by the server):

- `getLength()` to obtain the value from the standard OBEX header: `LENGTH`
- `getType()` to obtain the value from the standard OBEX header: `TYPE`

Once you have an `Operation` instance from the `get()` method call, you can call one of the following:

- `openInputStream()` to obtain an `InputStream`
- `openDataInputStream()` to obtain a `DataInputStream`

Once you have an `Operation` instance from a `put()` method call, you can call one of these methods:

- `openOutputStream()` to obtain an `OutputStream`
- `openDataOutputStream()` to obtain a `DataOutputStream`

With the stream opened, you can use the read or write methods of the stream to process the incoming or outgoing data object. The OBEX implementation underneath will perform the necessary segmenting of packets, sending them, and reassembling them for you. This is one of the primary benefits of using the OBEX high-level API instead of lower-level packet-based APIs.

You can close the stream once you are finished reading/writing. Note that once you close the stream, the OBEX implementation underneath will be sending packets to the server that indicate the operation is completed. The server will send a response code; this response code can be obtained using the following:

```
int getResponseCode();
```

■ **Caution** Do not call `getResponseCode()` unless you are finished with the stream you have obtained from the operation. Calling `getResponseCode()` will implicitly close the stream and signal to the server that the operation is completed. No further IO operations will be possible on the stream once `getResponseCode()` is called.

The `abort()` method may be used to abort a `GET` or `PUT` operation. It will close the operation's stream implicitly.

```
void abort();
```

Obtaining OBEX Client and Server Connections

When creating clients using OBEX over IrDA, the connection URL string provided to GCF's `Connector.open()` contains all the instructions necessary to work with the communications stack. The underlying implementation will parse the connection string for the instruction.

The general format is as shown here:

```
"irdaobex://{target};{parameters}"
```

If `{target}` begins with `discover`, the IrDA stack will perform discovery for accessible IrDA devices. The `{target}` of server connections always begins with `localhost`. A very useful parameter available for OBEX/IrDA is the `ias` parameter. The `ias` parameter is the string-based IAS class name used for server identification.

For example, a server application called `DatingService` can use the following connection string:

```
"irdaobex://localhost;ias=DatingService"
```

An OBEX client wishing to discover and connect to this service can simply use this connection string:

```
"irdaobex://discover;ias=DatingService"
```

The OBEX API extends the GCF with `SessionNotifier` for creating OBEX server connections. OBEX server code can wait for incoming client OBEX connections, blocking on an `acceptAndOpen()` call on a `SessionNotifier`.

See JSR 82 and documentation of your OBEX over IrDA implementation for more details on the available target and parameter values.

An OBEX Dating Service

Reusing the application logic from the Bluetooth dating service example earlier, this second example implements the same dating service using OBEX over infrared.

To try out this example, perform the following steps:

1. Using KToolbar, create a project called OBEXMIDlet.
2. Copy the source files to the `src` directory of OBEXMIDlet.

3. Build the project.
4. Set the MIDlet properties in Table 12-8.
5. Using KToolbar, create a project called OBEX2 with MIDlet name `OBEXMIDlet`.
6. Copy the source files to the `src` directory of OBEX2.
7. Build the project.
8. Set the MIDlet properties for OBEX2, with the values in Table 12-9.
9. Start an emulator instance of OBEX2 and launch the MIDlet.
10. Open the OBEXMIDlet project.
11. Start an emulator instance of OBEXMIDlet and launch the MIDlet.

Table 12-8. *MIDlet Properties for OBEXMIDlet Project*

Key	Value
OBEXMIDlet-mycontact	tallguy@yahoo.com
OBEXMIDlet-myheight	tall
OBEXMIDlet-mypref	male
OBEXMIDlet-seekheight	short
OBEXMIDlet-seekpref	female

Table 12-9. *MIDlet properties for OBEX2 Project*

Key	Value
OBEXMIDlet-mycontact	shortgal@yahoo.com
OBEXMIDlet-myheight	short
OBEXMIDlet-mypref	female
OBEXMIDlet-seekheight	tall
OBEXMIDlet-seekpref	male

Coding the OBEX Dating Service Client

Listing 12-3 shows `DateClient.java`, a singleton instance with the client logic in the `run()` method. The connector URL string used in `Connector.open()` is "irdaobex://discover;ias=DatingService". This provides the instruction for the underlying OBEX infrared transport to discover the associated dating service.

Listing 12-3. *An OBEX Dating Client—DateClient.java*

```
Import java.io.*;
import javax.microedition.io.*;
import javax.obex.*;

public final class DateClient implements Runnable {
    private Thread mClientThread = null;
    private static DateClient inst = new DateClient();
    private  DateClient() {
    }
    public static DateClient getInstance() {
        return inst;
    }
    private boolean mEndNow = false;
    private String mPref = null;
    private String mHeight = null;
    private String mContact = null;

    private static final String url =
    "irdaobex://discover;ias=DatingService";
    public void setMyInfo(String inPref, String inHeight,
    String inContact) {
        mPref = inPref;
        mHeight = inHeight;
        mContact = inContact;
    }
    public void startClient() {
        if (mClientThread != null)
            return;
        mEndNow = false;

        // Start receive thread
        mClientThread = new Thread(this);
        mClientThread.start();
    }
    public void stopClient() {
        mEndNow = true;
        try {
            // Only on CLDC 1.1
            // mClientThread.interrupt();
            mClientThread.join();
        } catch (Exception ex) {
            System.out.println("in stop client");
            ex.printStackTrace();
        }
        mClientThread = null;

    }
```

```
public void run() {
    DataOutputStream dos  = null;
    Operation op = null;
    ClientSession ses = null;
    int code = 0;
    HeaderSet resp = null;
    HeaderSet hdrs = null;

    while( !mEndNow)  {
        ses = null;
        dos = null;
        op = null;
        try  {
            ses = (ClientSession) Connector.open(url);
        } catch (IOException ex) {
            // Discovery fails, sleep for a while and try again
            try {
                Thread.sleep(3000l);
            } catch (Exception e) {}
            continue;
        }

        try {
            resp = ses.connect(null);
            code = resp.getResponseCode();

            if (code != ResponseCodes.OBEX_HTTP_OK) {
                throw new IOException("OBEX connect operation failed");
            }
            hdrs = ses.createHeaderSet();
            op = ses.put(hdrs);
            dos = null;
            dos = op.openDataOutputStream();


            if (dos != null)  {
                dos.writeUTF(mPref);
                dos.writeUTF(mHeight);
                dos.writeUTF(mContact);
                dos.flush();
                dos.close();

                code = op.getResponseCode();
                //   System.out.println("before os close");
                if (code != ResponseCodes.OBEX_HTTP_OK) {
                    throw new IOException("OBEX failure after put operations");
                }
```

```
                    //   System.out.println("before op close");

                    op.close();

                }

            } catch (Exception ex) {
                ex.printStackTrace();
            }
        }  // while
    } // run
}
```

In Listing 12-3, it would have been possible to use a custom header to send our dating information. However, this example uses a PUT operation, showing the code required to handle the more complex OBEX PUT operation instead.

Coding an OBEX Service

The service code and the GUI MIDlet code are in `OBEXMIDlet.java`, shown in Listing 12-4. The service is started in its own `mServer` thread. Note the use of the connect string "irdaobex://localhost;ias=DatingService" to create the `SessionNotifier` required to accept incoming OBEX over IrDA connections.

Listing 12-4. *An OBEX Dating Service—OBEXMIDlet.java*

```
import java.io.*;
import javax.microedition.midlet.*;
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.obex.*;

import java.io.IOException;

public class OBEXMIDlet
extends MIDlet
implements CommandListener, Runnable {
    private DateClient mClient = null;
    private Thread mServer = null;
    private OperationHandler mOpHandler = null;

    private Command mExitCommand  = new Command("Exit", Command.EXIT, 2);
    private Display mDisplay = null;
    private StringItem mDateContact = null;
    private Form mForm = null;
```

```
private boolean mEndNow = false;
private String mLastContact = "";



private String myPref = null;
private String myHeight = null;
private String myContact = null;

private String seekPref = null;
private String seekHeight = null;
private String seekContact = null;

private SessionNotifier mServerNotifier;
private static final String url =
    "irdaobex://localhost;ias=DatingService";
private Connection mConnection = null;


public OBEXMIDlet() {
    mClient = DateClient.getInstance();
    myPref = getAppProperty("OBEXMIDlet-mypref");
    myHeight = getAppProperty("OBEXMIDlet-myheight");
    myContact = getAppProperty("OBEXMIDlet-mycontact");
    seekPref = getAppProperty("OBEXMIDlet-seekpref");
    seekHeight = getAppProperty("OBEXMIDlet-seekheight");

}

public void commandAction(Command c, Displayable d) {
    if (c == mExitCommand) {
        destroyApp(true);
        notifyDestroyed();
    }
}


protected void destroyApp(boolean param) {
    mEndNow = true;
    if (mServerNotifier != null) {
        try {
            mServerNotifier.close();
        } catch (IOException e) {} // Ignore
    }
```

```
        // Wait until acceptor thread is done
        try {
            mServer.join();
        } catch (InterruptedException e) {} // Ignore
        try {
            mClient.stopClient();
        } catch (Exception e) {} // Ignore

    }

    protected void pauseApp() {

    }

    protected void startApp() {
        if (mForm == null) {
            mForm = new Form("OBEXMIDlet");
            mDateContact = new StringItem("Potential date found at:",null);
            mForm.append(mDateContact);
            mForm.addCommand(mExitCommand);
            mForm.setCommandListener(this);
        }
        mDisplay = Display.getDisplay(this);
        mDisplay.setCurrent(mForm);
        mEndNow = false;
        startServer();
        mClient.setMyInfo(myPref, myHeight, myContact);
        mClient.startClient();
        mOpHandler = new OperationHandler(this);
    }
    private void startServer() {
        if (mServer != null)
            return;
        // Start server thread
        mServer = new Thread(this);
        mServer.start();

    }

    public void run() {
        try {
            mServerNotifier = (SessionNotifier) Connector.open(url);
        } catch (Exception e) {
            System.err.println("Can't initialize OBEX server: " + e);
        }
```

```
    while (!mEndNow) {
        mConnection = null;

        try {
            mConnection = mServerNotifier.acceptAndOpen(mOpHandler);
        } catch (IOException e) {
            continue;
        }


        //          System.out.println(" got a connection!");
        try {
            // Bad bad API design, need to synchronize server thread
            synchronized(this) {
                this.wait();
            }

            //       System.out.println("svr: before conn close");
            mConnection.close();
        } catch (Exception ex) {
            // Log exception
        }

    }  // of while
    try {
        mServerNotifier.close();
    } catch (Exception ex) {
        System.out.println("trying to close session...exception");
        ex.printStackTrace();
    }
}


private void processRequest(DataInputStream dis) {
    String pref = null;
    String height = null;
    String contact = null;
    try {
        pref = dis.readUTF();
        height = dis.readUTF( );
        contact = dis.readUTF();

                dis.close();
    } catch (IOException e) {
        System.out.println("in process request exception");
        e.printStackTrace();
    }
```

```
        if (! mLastContact.equals(contact)) {
            mLastContact = contact;
            if (pref.equals(seekPref)  && height.equals(seekHeight))
                mDisplay.callSerially(new ShowCandidate(contact));
        }
    }

    class OperationHandler extends ServerRequestHandler {
        DataInputStream dis = null;
        Object syncObject = null;
        public OperationHandler( Object inSync) {
            syncObject = inSync;
        }
        public int onPut(Operation op) {
            dis = null;
            try {
                dis = op.openDataInputStream();
            } catch (Exception ex) {
                // Okay for CREATE_EMPTY op
            }
            if (dis != null)   // Not a  CREATE_EMPTY op
            {
                processRequest(dis);
                try {
                    dis.close();
                    op.close();
                } catch (Exception ex) {
                }
                dis = null;
                synchronized(syncObject) {
                    syncObject.notify();
                }
            }
            return ResponseCodes.OBEX_HTTP_OK;
        }
    }
```

```
    class ShowCandidate implements Runnable {
        Display disp = null;
        String contact = null;
        public ShowCandidate(String cont) {
            contact = cont;
        }
        public void run() {
            mDateContact.setText(contact );
        }
    }

}
```

OBEX server handling uses a listener inherited from `ServerRequestHandler`. In Listing 12-4, the private `OperationHandler` is used for this purpose. Since the OBEX callback is performed on a system thread, the actual work of `processRequest()` is not performed there. Instead, thread synchronization is used to ensure that the work is performed on the `mServer` thread.

Summary

The Java API for Bluetooth is an optional API that provides MIDP applications with access to a device's support for radio connectivity with nearby devices. Using Bluetooth, devices can offer services to one another, or consume services provided by nearby network resources. You use the familiar CLDC GCF when working with Bluetooth connections.

JSR 82 specifies the Java API for Bluetooth, as well as an API for the OBEX protocol. The OBEX protocol provides a simple and standard way of creating communicating MIDP applications that utilizes the infrared link hardware available on some devices.

CHAPTER 13

Programming a Custom User Interface

Chapters 5, 6, and 7 were devoted to MIDP's generalized user-interface APIs. Clever as these APIs are, they are unsuitable for game development and other specialized user interfaces. Games are programmed "closer to the metal" than other applications. MIDP offers a class, `javax.microedition.lcdui.Canvas`, that provides low-level access to a device's screen and input facilities. You can find out exactly which keys a user is pressing and draw whatever you want on the screen.

The Game API, contained in the `javax.microedition.lcdui.game` package, includes a refinement of `Canvas` and classes for layer-based graphics and sprite animations. The Game API is fully discussed in Chapter 14. In this chapter, you'll learn the basics of `Canvas` and drawing with the `Graphics` class.

The Canvas Class

`Canvas` is the heart of MIDP's custom user-interface API. To use it, you must create a subclass of `Canvas`. This differs from the `Screen` subclasses, which are ready to use "out of the box."

Aside from that, however, `Canvas` fits in very nicely with the other subclasses of `Displayable`. A MIDlet can mix and match regular screens and `Canvas`es. In a game, for instance, a high-score screen might be a `Form`, while the game itself would be played on a `Canvas`.

`Canvas` contains event-handling methods that are invoked by the MIDP implementation whenever something important happens. When the user presses a key, or when the screen needs to be painted, one of `Canvas`'s methods will be called. Most of these methods have empty implementations in `Canvas`. To respond to an event, you need to override the appropriate method and provide an implementation.

The one exception to this rule is the `paint()` method, which is declared abstract and thus must be defined in subclasses.

Canvas Information

If you would like to draw your own user interface, you'll need some basic information about the `Canvas`. You can find out the size of the `Canvas` by calling `getWidth()` and `getHeight()`. As we'll discuss later, you can also find out the color capabilities of the device by calling methods in `Display`.

There is also a full-screen mode. Some `Canvas` implementations won't occupy all the available screen space, reserving areas of the screen for information about the state of the device or other purposes. If the device supports an alternate full screen mode for `Canvas`, you can use it by calling `setFullScreenMode(true)`. Setting full screen mode on or off may result in calls to the `sizeChanged()` method `Canvas` inherits from `Displayable`.

`Canvas` also features event handler methods that will be called by the MIDP implementation as your `Canvas` is displayed and hidden. Each time your `Canvas` is shown, the `showNotify()` method will be called. If another `Displayable` is shown, or the application manager decides to run a different application, `hideNotify()` is called.

Painting and Repainting

The MIDP implementation calls a `Canvas`'s `paint()` method when the contents of the `Canvas` need to be shown. This `paint()` method should look familiar to anyone who has ever implemented a custom Swing or AWT component.

The MIDP implementation passes a `Graphics` object to your `paint()` method. `Graphics` has methods for drawing shapes, text, and images on a `Canvas`. A typical `Canvas` implementation, then, looks something like this:

```
import javax.microedition.lcdui.*;

public class JonathanCanvas
    extends Canvas {
  public void paint(Graphics g) {
    // Draw stuff using g.
  }
}
```

What if you want to tell the `Canvas` to draw itself? You can't call `paint()` directly, because you don't have a suitable `Graphics` to pass to `paint()`. Instead, you need to tell the MIDP implementation that it's time to paint the `Canvas`. The way you do this is by calling `repaint()`. The first version of this method simply tells `Canvas` to paint everything.

```
public void repaint()
public void repaint(int x, int y, int width, int height)
```

The second version is a way of saying, "I only want you to paint this rectangular portion of the screen." If the drawing you're doing is very complicated, you can save some time by only painting the portion of the `Canvas` that has changed. This is implemented using a technique called clipping. A later section discusses clipping in more detail.

How exactly does `repaint()` work? When you call `repaint()`, `paint()` won't be called right away. The call to `repaint()` just signals to the MIDP implementation that you want the screen to be painted. Some time later, the implementation *services* the repaint request, which results in an actual call to the `paint()` method of the `Canvas`. The MIDP implementation may even combine several repaint requests, particularly if their repaint regions overlap.

■ **Tip** Canvas does not automatically clear itself when you call `repaint()`. If you want to change what's on the screen, rather than adding to it, you should clear the screen in the `paint()` method. You'll see how to do this in the `FontCanvas` example later in this chapter.

An application can force the implementation to service all the repaint requests by calling `serviceRepaints()` on the `Canvas` object. This method does not return until all pending repaint requests have been serviced. If you are going to call `serviceRepaints()`, you should make sure that you aren't trying to acquire object locks in the `paint()` method that won't be released until `serviceRepaints()` returns. In general, you won't need to call `serviceRepaints()`; you can usually use `Display`'s `callSerially()` method instead. (See the "Multithreading and Animation" section of this chapter for a discussion of `callSerially()`.)

Drawing Shapes, Text, and Images

The `Graphics` class contains methods for drawing shapes, text, and images on a `Canvas`. It also maintains some state, like the current pen color and line style. MIDP's `Graphics` class is similar to the `Graphics` and `Graphics2D` classes in J2SE but much smaller.

Coordinate Space

All drawing on a `Canvas` takes place in a coordinate space based on the pixels of the device. By default, the origin of this coordinate space is located in the upper-left corner of the `Canvas`. X coordinates increase in the right-hand direction, while Y coordinates increase in the downward direction, as shown in Figure 13-1.

You can adjust the origin of this coordinate space by calling the `translate()` method of the `Graphics` class. This sets the origin to the given coordinates in the current coordinate system. To find out the location of the translated origin relative to the default origin, call `getTranslateX()` and `getTranslateY()`.

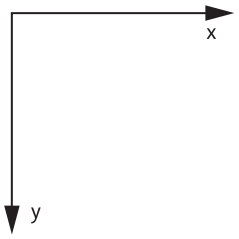


Figure 13-1. *Canvas coordinate axes*

Drawing and Filling Shapes

`Graphics` contains a collection of methods that draw and fill simple shapes. These are detailed in Table 13-1.

Table 13-1. *Drawing and Filling Shapes with Graphics*

Shape Outline	Filled Shape
`drawLine(int x1, int y1, int x2, int y2)`	
	`fillTriangle(int x1, int y1, int x2, int y2, int x3, int y3)`
`drawRect(int x, int y, int width, int height)`	`fillRect(int x, int y, int width, int height)`
`drawRoundRect(int x, int y, int width, int height, int arcWidth, int arcHeight)`	`fillRoundRect(int x, int y, int width, int height, int arcWidth, int arcHeight)`
`drawArc(int x, int y, int width, int height, int startAngle, int arcAngle)`	`fillArc(int x, int y, int width, int height, int startAngle, int arcAngle)`

These methods do basically what you'd expect. The following example demonstrates some simple drawing using `Graphics`. It consists of two pieces. First, `PacerCanvas` demonstrates some simple drawing and filling:

```
import javax.microedition.lcdui.*;

public class PacerCanvas
    extends Canvas {
  public void paint(Graphics g) {
    int w = getWidth();
    int h = getHeight();

    g.setColor(0xffffff);
    g.fillRect(0, 0, w, h);
    g.setColor(0x000000);

    for (int x = 0; x < w; x += 10)
      g.drawLine(0, w - x, x, 0);

    int z = 50;
    g.drawRect(z, z, 20, 20);
    z += 20;
    g.fillRoundRect(z, z, 20, 20, 5, 5);
    z += 20;
    g.drawArc(z, z, 20, 20, 0, 360);
  }
}
```

The next class is `Pacer`, a MIDlet that uses `PacerCanvas`.

```
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
```

```
public class Pacer
    extends MIDlet{
  public void startApp() {
    Displayable d = new PacerCanvas();

    d.addCommand(new Command("Exit", Command.EXIT, 0));
    d.setCommandListener(new CommandListener() {
      public void commandAction(Command c, Displayable s) {
        notifyDestroyed();
      }
    } );

    Display.getDisplay(this).setCurrent(d);
  }

  public void pauseApp() { }

  public void destroyApp(boolean unconditional) { }
}
```

When you run `Pacer` in the Wireless Toolkit emulator, it looks like Figure 13-2.

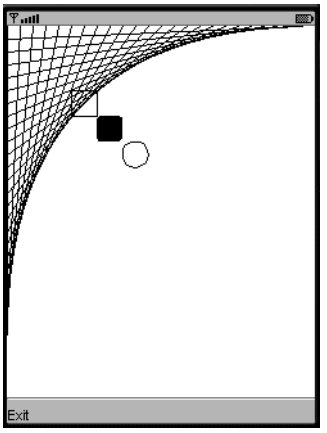


Figure 13-2. *Playing around with Graphics*

Working with Color

The `Graphics` class maintains a current drawing color that is used for drawing shape outlines, filling shapes, and drawing text. `Colors` are represented as combinations of red, green, and blue, with 8 bits for each color component. You can set the current drawing color using the following method:

```
public void setColor(int RGB)
```

This method expects the red, green, and blue values in a packed integer, as shown in Figure 13-3.

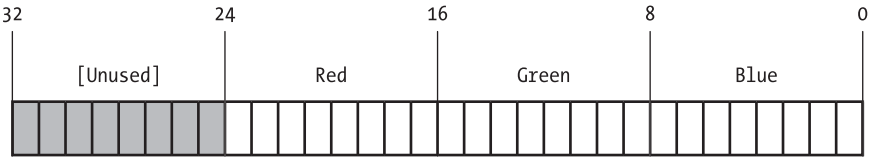


Figure 13-3. *Packing a color into an integer*

An alternate convenience method accepts red, green, and blue values as integers in the range from 0 to 255 inclusive:

```
public void setColor(int red, int green, int blue)
```

You can retrieve the current drawing color (as a packed integer) with `getColor()`. Alternatively, you can retrieve each component separately using `getRedComponent()`, `getGreenComponent()`, and `getBlueComponent()`.

Of course, different devices will have different levels of color support, from black and white (affectionately known as "1-bit color") through full 24-bit color. As we mentioned in Chapter 5, the `isColor()` and `numColors()` methods in `Display` return useful information about the capabilities of the device.

For grayscale devices, `Graphics` provides `setGrayScale()` as a convenience method. You pass it a number from 0 (black) to 255 (white). You can find out the current grayscale value by calling `getGrayScale()`. If the current color of this `Graphics` is not a grayscale color (that is, if the red, green, and blue values of the current color are not the same), then this method returns its best guess as to the brightness of the current color.

Another handy method in the `Graphics` class is `getDisplayColor()`. This method can tell you at runtime exactly how a requested color will be displayed on the device. You feed it a color `int`, and it returns the color `int` that will actually be displayed on the device. For example, on the WTK's `DefaultGrayPhone` emulator, pure green (`0x00ff00`) maps to the gray level `0x959595`.

Line Styles

`Graphics` also maintains a current line style, called a stroke style, that is used for drawing shape outlines and lines. There are two choices for line style, represented by constants in the `Graphics` class:

- `SOLID` is the default.
- `DOTTED` lines may also be drawn.

It's up to the implementation to decide exactly how dotted lines are implemented, so dotted lines on one device may look dashed on another. You can set or retrieve the current style using `setStrokeStyle()` and `getStrokeStyle()`. For example, the following code draws a square with a solid outline (the default) and another square with a dotted outline:

```
public void paint(Graphics g) {
  g.drawRect(20, 10, 35, 35);
  g.setStrokeStyle(Graphics.DOTTED);
  g.drawRect(20, 60, 35, 35);
}
```

Drawing Text

The `Graphics` class makes it easy to draw text anywhere on the screen. Text drawing is based around the idea of an anchor point. The anchor point determines exactly where the text will be drawn. Anchor points are described with a horizontal and vertical component. The `Graphics` class defines the horizontal and vertical anchor points as constants. Figure 13-4 illustrates the various anchor points for a string of text. Each anchor point is described as a combination of a horizontal and vertical anchor point.

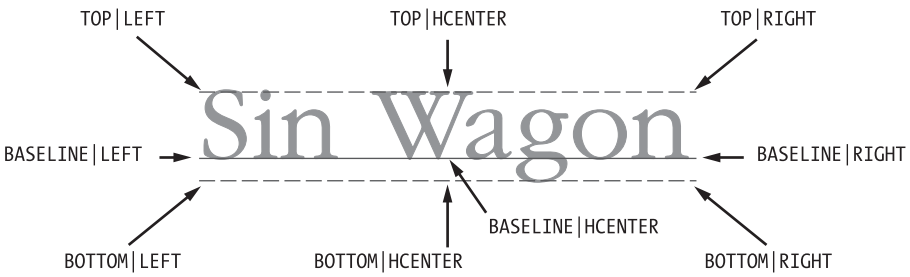


Figure 13-4. *Text anchor points*

To draw text, you just need to specify the text itself and the location and type of anchor point. You could, for example, place some text in the upper-left corner of the screen by using a `TOP | LEFT` anchor point located at 0, 0.

Text is specified as a `String` or an array of `chars`, which means you can draw text in many languages, provided that the fonts you're using have the corresponding glyphs.

`Graphics` provides four different methods for drawing text. You can draw characters or `String`s, depending on what you have available:

```
public void drawChar(char character, int x, int y, int anchor)
public void drawChars(char[] data, int offset, int length,
    int x, int y, int anchor)
public void drawString(String str, int x, int y, int anchor)
public void drawSubstring(String str, int offset, int len,
    int x, int y, int anchor)
```

The following example shows how to place text at various places on a `Canvas`:

```
import javax.microedition.lcdui.*;

public class TextCanvas
    extends Canvas {
  public void paint(Graphics g) {
    int w = getWidth();
    int h = getHeight();

    g.setColor(0xffffff);
    g.fillRect(0, 0, w, h);
    g.setColor(0x000000);


    // First label the four corners.
    g.drawString("corner", 0, 0,
        Graphics.TOP | Graphics.LEFT);
    g.drawString("corner", w, 0,
        Graphics.TOP | Graphics.RIGHT);
    g.drawString("corner", 0, h,
        Graphics.BOTTOM | Graphics.LEFT);
    g.drawString("corner", w, h,
        Graphics.BOTTOM | Graphics.RIGHT);

// Now put something in the middle (more or less).
    g.drawString("Sin Wagon", w / 2, h / 2,
        Graphics.BASELINE | Graphics.HCENTER);
  }
}
```

To see this `Canvas`, you'll have to create a MIDlet that displays it. We suggest using `Pacer`; just edit the source file so it instantiates a `TextCanvas` instead of a `PacerCanvas`. The finished product is shown in Figure 13-5.

Note that `Canvas` denies us some real estate at the bottom of the screen. This is to allow space for commands. `Canvas`, like any other `Displayable`, can display commands and have a command listener.

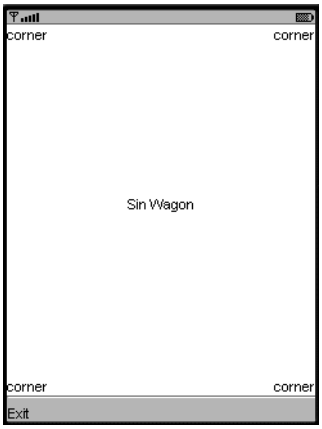


Figure 13-5. *TextCanvas in the flesh*

Selecting a Font

MIDP fonts are represented by a `font face`, `style`, and `size`. You won't find a big selection of fonts, but there are a few choices. Three faces are available, as shown in Figure 13-6. These are represented by constants in the `Font` class: `FACE_SYSTEM`, `FACE_MONOSPACE`, and `FACE_PROPORTIONAL`.

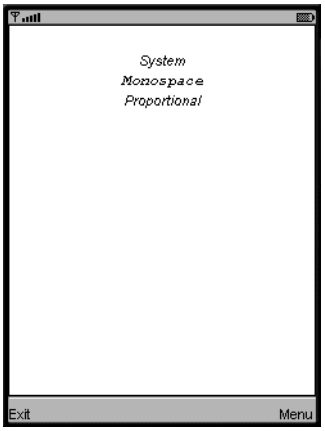


Figure 13-6. *The three font faces in italics*

Once you've chosen a font face, you can also specify a style and a size. The styles are what you'd expect, and they are represented by constants in the `Font` class: `STYLE_PLAIN`, `STYLE_BOLD`, `STYLE_ITALIC`, and `STYLE_UNDERLINE`. You can combine styles, like bold and italic, by ORing the constants together. The size is simply `SIZE_SMALL`, `SIZE_MEDIUM`, or `SIZE_LARGE`.

You could create a small, italic, proportional font with the following call:

```
Font f = Font.getFont(
    Font.FACE_PROPORTIONAL,
    Font.STYLE_ITALIC,
    Font.SIZE_SMALL);
```

To tell `Graphics` to use a new font for subsequent text, call `setFont()`. You can get a reference to the current font by calling `getFont()`. You can also find out information about a `Font` with the `getFace()`, `getStyle()`, and `getSize()` methods. For convenience, `Font` also includes the `isPlain()`, `isBold()`, `isItalic()`, and `isUnderlined()` methods.

The MIDP implementation has a default font that you can retrieve from `Font`'s static method `getDefaultFont()`.

The following `Canvas` demonstrates the creation and use of fonts:

```
import javax.microedition.lcdui.*;

public class FontCanvas
    extends Canvas {
  private Font mSystemFont, mMonospaceFont, mProportionalFont;

  public FontCanvas() { this(Font.STYLE_PLAIN); }

  public FontCanvas(int style) { setStyle(style); }

  public void setStyle(int style) {
    mSystemFont = Font.getFont(Font.FACE_SYSTEM,
        style, Font.SIZE_MEDIUM);
    mMonospaceFont = Font.getFont(Font.FACE_MONOSPACE,
        style, Font.SIZE_MEDIUM);
    mProportionalFont = Font.getFont(Font.FACE_PROPORTIONAL,
        style, Font.SIZE_MEDIUM);
  }

  public boolean isBold() {
    return mSystemFont.isBold();
  }
  public boolean isItalic() {
    return mSystemFont.isItalic();
  }
  public boolean isUnderline() {
    return mSystemFont.isUnderlined();
  }

  public void paint(Graphics g) {
    int w = getWidth();
    int h = getHeight();
```

```
    // Clear the Canvas.
    g.setGrayScale(255);
    g.fillRect(0, 0, w - 1, h - 1);
    g.setGrayScale(0);
    g.drawRect(0, 0, w - 1, h - 1);

    int x = w / 2;
    int y = 20;

    y += showFont(g, "System", x, y, mSystemFont);
    y += showFont(g, "Monospace", x, y, mMonospaceFont);
    y += showFont(g, "Proportional", x, y, mProportionalFont);
  }

  private int showFont(Graphics g, String s, int x, int y, Font f) {
    g.setFont(f);
    g.drawString(s, x, y, Graphics.TOP | Graphics.HCENTER);
    return f.getHeight();
  }
}
```

To see this `Canvas` in action, you'll need a MIDlet that shows it. You could modify `Pacer` again, if you wish, or use the following code:

```
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;

public class FontMIDlet
    extends MIDlet
    implements CommandListener {
  private FontCanvas mFontCanvas;
  private Command mBoldCommand, mItalicCommand, mUnderlineCommand;

  public FontMIDlet() {
    mFontCanvas = new FontCanvas();

    mBoldCommand = new Command("Bold", Command.SCREEN, 0);
    mItalicCommand = new Command("Italic", Command.SCREEN, 0);
    mUnderlineCommand = new Command("Underline", Command.SCREEN, 0);
    Command exitCommand = new Command("Exit", Command.EXIT, 0);

    mFontCanvas.addCommand(mBoldCommand);
    mFontCanvas.addCommand(mItalicCommand);
    mFontCanvas.addCommand(mUnderlineCommand);
    mFontCanvas.addCommand(exitCommand);
    mFontCanvas.setCommandListener(this);
  }
```

```
  public void startApp() {
    Display.getDisplay(this).setCurrent(mFontCanvas);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT) {
      notifyDestroyed();
      return;
    }


    boolean isBold = mFontCanvas.isBold() ^ (c == mBoldCommand);
    boolean isItalic = mFontCanvas.isItalic() ^ (c == mItalicCommand);
    boolean isUnderline = mFontCanvas.isUnderline() ^
        (c == mUnderlineCommand);

    int style =
        (isBold ? Font.STYLE_BOLD : 0) |
        (isItalic ? Font.STYLE_ITALIC : 0) |
        (isUnderline ? Font.STYLE_UNDERLINED : 0);

    mFontCanvas.setStyle(style);
    mFontCanvas.repaint();
  }
}
```

Measuring Text

The `Font` class can tell you useful information about the dimensions of text. If you read the previous example carefully, you'll notice we already used one of these methods, `getHeight()`. This method returns the height of an entire line of text and can be used to position multiple lines.

If you really need to know the location of the baseline, call `getBaselinePosition()`. This returns the distance from the top of a line of text to the baseline. However, given the flexibility offered by the anchor points in `Graphics`, you probably won't ever need to find the baseline yourself.

The rest of the methods in `Font` for measuring text measure the width of various pieces of text. The names and parameters of these methods are the same as text drawing methods in `Graphics`:

```
public int charWidth(char ch)
public int charsWidth(char ch, int offset, int length)
public int stringWidth(String str)
public int substringWidth(String str, int offset, int len)
```

You could draw a box around a string, for example:

```
import javax.microedition.lcdui.*;

public class BoxTextCanvas
    extends Canvas {
  private Font mFont;

public BoxTextCanvas() {
    mFont = Font.getFont(Font.FACE_PROPORTIONAL,
        Font.STYLE_PLAIN, Font.SIZE_LARGE);
  }

  public void paint(Graphics g) {
    int w = getWidth();
    int h = getHeight();

    g.setColor(0xffffff);
    g.fillRect(0, 0, w, h);
    g.setColor(0x000000);

    String s = "dolce";
    int stringWidth = mFont.stringWidth(s);
    int stringHeight = mFont.getHeight();
    int x = (w - stringWidth) / 2;
    int y = h / 2;

    g.setFont(mFont);
    g.drawString(s, x, y, Graphics.TOP | Graphics.LEFT);
    g.drawRect(x, y, stringWidth, stringHeight);
  }
}
```

Drawing Images

The `Graphics` class contains a single method for drawing an image:

```
public void drawImage(Image img, int x, int y, int anchor)
```

The `drawImage()` method uses an anchor point, just like the anchor point in the text drawing methods. The available anchor points are slightly different. `BASELINE` is no longer an option for the vertical anchor point of an image, as the concept of baseline is specific to text. Instead, `VCENTER` is an additional option for the vertical anchor point. Figure 13-7 shows the available combinations of anchor points.

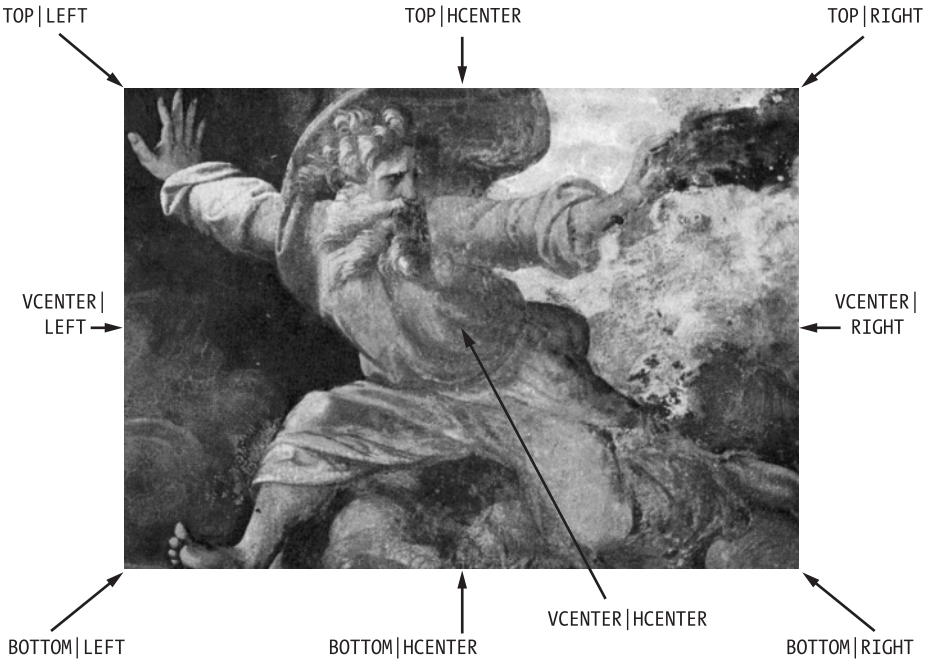


Figure 13-7. *Image anchor points*

Advanced Image Rendering

The `Graphics` class also includes a `drawRegion()` method for rendering a region of an image and possibly manipulating it at the same time. The method looks like this:

```
public void drawRegion(Image src,
    int x_src, int y_src, int width, int height,
    int transform, int x_dest, int y_dest, int anchor)
```

The `x_src`, `y_src`, `width`, and `height` parameters describe a rectangular region of the image that will be rendered on the drawing surface of the `Graphics`. The region is drawn at `x_dest` and `y_dest` subject to the `anchor`, just as in the `drawImage()` method.

The `transform` parameter opens up a whole new world of possibilities. It may be any of the transformations described by constants in the `Sprite` class, listed here. (`Sprite` is part of the Game API and is described in the next chapter.)

- `TRANS_NONE`
- `TRANS_ROT90`
- `TRANS_ROT180`
- `TRANS_ROT270`
- `TRANS_MIRROR`
- `TRANS_MIRROR_ROT90`

- TRANS_MIRROR_ROT180
- TRANS_MIRROR_ROT270

The ROT transformations rotate the source image region by 90, 180, or 270 degrees. The MIRROR_ROT transformations first mirror the region around its vertical center, and then rotate the mirrored region.

The drawRegion() method allows easy manipulation and display of animation frames that are packed into a single image.

Images As Integer Arrays

You've already seen how a single color can be represented as an integer. By extension, an image can be represented as an array of integers, where each integer in the array contains the color for a single pixel in the image.

Rendering integer arrays as images is supported with the following method:

```
public void drawRGB(int[] rgbData, int offset, int scanlength,
    int x, int y, int width, int height,
    boolean processAlpha)
```

The image data is contained in the rgbData array, starting at offset. Consecutive rows of data are contained at offsets measured by multiples of scanlength. The image will be rendered at x and y with a size defined by width and height.

The relationship between width and scanlength is a little confusing at first. The following example should clear things up.

Consider the following code.

```
int[] rgbData = {
  0x123456, 0x123456, 0x123456,
  0x000000, 0xffffff, 0xffffff, 0x000000, 0x654321, 0x654321,
  0x000000, 0x000000, 0xffffff, 0x000000, 0x654321, 0x654321,
  0x000000, 0xffffff, 0x000000, 0x000000, 0x654321, 0x654321,
  0x000000, 0xffffff, 0xffffff, 0x000000, 0x654321, 0x654321
};

g.drawRGB(rgbData, 3, 6, 10, 10, 4, 4, false);
```

This code produces the very small image shown at great magnification in Figure 13-8. The first three elements of the array are ignored by passing an offset of 3. Although the image width is 4 pixels, each row of data is separated by 6 positions in the integer array. The image will be rendered at 10, 10, with a size of 4 by 4 pixels.

Figure 13-8. *A very small image*

The final parameter in the `drawRGB()` method, `processAlpha`, indicates whether the integer array is considered to contain an alpha (opacity) component. If the parameter is `false`, every pixel of the image is considered fully opaque. If `processAlpha` is `true`, the opacity of each pixel is determined by the high-order byte of the integer value, and the pixel's color will be blended with the drawing surface appropriately. An alpha value of 0 is fully transparent, while an alpha value of 255 is fully opaque.

Blitting

Blitting, the copying of one region of the screen to another location, is a crucial operation for some types of games. There is one method of the `Graphics` class that can be used for blitting:

```
public void copyArea(int x_src, int y_src, int width, int height,
    int x_dest, int y_dest, int anchor)
```

This method is pretty self-explanatory. It copies a portion of the screen, described by `x_src`, `y_src`, `width`, and `height`, to a destination described by `x_dest`, `y_dest`, and `anchor`. The anchor works the same as for the `drawImage()` method.

This method works only on a `Graphics` object that does not draw directly to the screen. A `Graphics` object that draws to an image is fine, as is a `Graphics` object that works on a double-buffered `Canvas`. A `Graphics` object from `GameCanvas`'s `getGraphics()` method will also work. By contrast, a `Graphics` object for a non-double-buffered `Canvas` will throw an `IllegalStateException` if the `copyArea()` method is called. (See the upcoming section on double buffering for more information on the technique.)

Clipping

`Graphics` maintains a rectangular `clipping shape`. The clipping shape limits drawing, such that any drawing that takes place outside of the clipping shape will not be displayed. It's kind of like painting through a stencil, except you can only use a rectangular stencil. If you were writing a game that had some kind of border on the game board, you might set the clipping rectangle to be the inside of the game board, so that no drawing could overwrite the border.

You can find out the current clipping rectangle by calling `getClipX()`, `getClipY()`, `getClipWidth()`, and `getClipHeight()`.

If you would like to modify the clipping rectangle, there are two methods that you can use. First, you can set the clipping rectangle directly by calling the following method:

```
public void setClip(int x, int y, int width, int height);
```

The other possibility is to limit the current clipping rectangle with another rectangle. The following method takes the intersection of the current clipping rectangle and the supplied rectangle and uses it to set the new clipping rectangle:

```
public void clipRect(int x, int y, int width, int height);
```

Key Events

`Canvas` handles events at a lower level than the other `Displayable` subclasses. Although you can add `Commands` and respond to them, `Canvas` also includes a set of methods that handle interaction with the individual keys of a device.

The following methods are called whenever the user presses and releases a key:

```
protected void keyPressed(int keyCode)
protected void keyReleased(int keyCode)
```

The key code that is passed to these methods will most likely be one of the constants defined in `Graphics`, from `KEY_NUM0` through `KEY_NUM9` and including `KEY_STAR` and `KEY_POUND`. Devices may have more keys than this, which will be returned as device-specific key codes. Assuming there's an obvious mapping between the key and some Unicode character, the rule of thumb is that a key should have a code equal to its Unicode character value. Keys that don't have a Unicode mapping should use negative values. This means that, given a positive key code, you can find out the corresponding Unicode character by casting the `int` key code to `char`.

Note that key presses and key releases are separate events, which allows you considerable flexibility in how you design your user interface. The time between the press and the release could determine how high a game character jumps or how powerful a laser blast will be.

Depending on the device and the MIDP implementation, a key that is held down may spit out repeated key events. You can find out if repeated keys are supported by calling `hasRepeatEvents()`. If repeated key events are supported, the `keyRepeated()` method will be called with these events.

Finally, you can find a text description of a given key code by calling `getKeyName()`.

The Game API offers a mechanism to bypass the key event callback methods. You can poll the state of the device's keys directly using a method in `GameCanvas`. For more information, see the following chapter.

Game Actions

Key codes may be useful in certain situations, but they're fairly specific to a device. MIDP offers a simple abstraction called a *game action* that makes it easier to map user key events to events that will be useful for games and other applications with specialized user interfaces.

The concept is simple: supply a key code to `getGameAction()`, and you'll receive a game action—one of the following values: `UP`, `DOWN`, `LEFT`, `RIGHT`, `FIRE`, `GAME_A`, `GAME_B`, `GAME_C`, or `GAME_D`. Basically game actions are a way to map the physical keys on a device to a set of video game buttons such as you might find on game platforms like Sega Genesis or Nintendo Game Boy.

To understand how this maps to a physical device, think about how you might map the `UP`, `DOWN`, `LEFT`, and `RIGHT` game actions to keys. On the WTK emulator, there are navigation keys that have an obvious relationship to these game actions. Think about a simpler phone, however, one that has only a numeric keypad. In this case, you might want to map `UP` to the 2 key, `DOWN` to the 8 key, `LEFT` to the 4 key, and `RIGHT` to the 6 key.

Using game actions saves you from having to make these decisions yourself; the MIDP implementation simply provides a reasonable mapping for the device. To find the game action for a key code, pass the key code to `getGameAction()`. You can also find the key code for a game action by calling `getKeyCode()`.

The following example listens for key presses in the `keyPressed()` method. It converts the key code to a game action and displays the game action on the screen.

```
import javax.microedition.lcdui.*;

public class KeyCanvas
    extends Canvas {
  private Font mFont;
  private String mMessage = "[Press keys]";

  public KeyCanvas() {
    mFont = Font.getFont(Font.FACE_PROPORTIONAL,
        Font.STYLE_PLAIN, Font.SIZE_MEDIUM);
  }

  public void paint(Graphics g) {
    int w = getWidth();
    int h = getHeight();

    // Clear the Canvas.
    g.setGrayScale(255);
    g.fillRect(0, 0, w - 1, h - 1);
    g.setGrayScale(0);
    g.drawRect(0, 0, w - 1, h - 1);

    g.setFont(mFont);

    int x = w / 2;
    int y = h / 2;

    g.drawString(mMessage, x, y, Graphics.BASELINE | Graphics.HCENTER);
  }

  protected void keyPressed(int keyCode) {
    int gameAction = getGameAction(keyCode);
    switch(gameAction) {
      case UP:     mMessage = "UP";             break;
      case DOWN:   mMessage = "DOWN";           break;
      case LEFT:   mMessage = "LEFT";           break;
      case RIGHT:  mMessage = "RIGHT";          break;
      case FIRE:   mMessage = "FIRE";           break;
      case GAME_A: mMessage = "GAME_A";         break;
      case GAME_B: mMessage = "GAME_B";         break;
      case GAME_C: mMessage = "GAME_C";         break;
      case GAME_D: mMessage = "GAME_D";         break;
      default:     mMessage = ""; break;
    }
    repaint();
  }
}
```

To run this example, you'll need a corresponding MIDlet to display `KeyCanvas`. At this point, we think you should be able to do this by yourself.

Pointer Events

Some devices, particularly PDAs, may support a pointer. The popular Palm platform, for example, is based around the use of a stylus and a touch-sensitive screen. You can find out at runtime if your device supports pointer events by calling `hasPointerEvents()` and `hasPointerMotionEvents()`. If the device supports pointer events, the following methods get called when the pointer is pressed and released:

```
protected void pointerPressed(int x, int y)
protected void pointerReleased(int x, int y)
```

If the device supports pointer motion events, the following method will be called as the user drags the stylus around the screen:

```
protected void pointerDragged(int x, int y);
```

Double Buffering

Double buffering is a well-known technique for reducing flicker in drawing and animations. Imagine you are implementing an animation that clears and redraws the entire screen for each frame of the animation. Without double buffering, the animation will flicker badly as the screen is cleared and redrawn. With double buffering, the new frame is drawn into an off-screen image (the buffer). When the off-screen drawing is complete, the image is drawn on the screen in one smooth, quick move. You pay a price in the memory that's needed for the off-screen image, but the improvement in the quality of the animation is dramatic.

The MIDP implementation may provide double buffering by default. You can find out whether a `Canvas` is double buffered by calling the `is DoubleBuffered()` method.

If the implementation does not give you double buffering, you'll have to do it yourself. Fortunately, it's not terribly difficult. The process looks like this:

1. Create an off-screen image by calling the static `Image.createImage(int width, int height)` method.
2. Obtain a `Graphics` that draws *into the image* by calling `getGraphics()` on the `Image`.
3. Draw stuff into the off-screen image using the `Graphics` object.
4. In the `paint()` method of the `Canvas`, use `drawImage()` to put the off-screen image on the `Canvas`.

Here's a `Canvas` subclass that creates a simple off-screen image and displays it:

```
import javax.microedition.lcdui.*;

public class OffscreenCanvas
    extends Canvas {
  private Image mImage;


  public void paint(Graphics g) {
    if (mImage == null)
      initialize();
    g.drawImage(mImage, 0, 0, Graphics.TOP | Graphics.LEFT);
  }

  private void initialize() {
    int w = getWidth();
    int h = getHeight();

    mImage = Image.createImage(w, h);

    Graphics g = mImage.getGraphics();

    g.drawRect(0, 0, w - 1, h - 1);
    g.drawLine(0, 0, w - 1, h - 1);
    g.drawLine(w - 1, 0, 0, h - 1);
  }
}
```

Multithreading and Animation

As with any graphic-interface toolkit, threading with the MIDP user-interface classes is a little tricky. The user-interface implementation has its own thread that handles both user-interface methods and screen painting. For example, when the user presses a key on their device, the implementation calls `keyPressed()` in your `Canvas` subclass. The thread that calls this method belongs to the MIDP implementation. As such, it should be handled with some care. In MIDP implementations, the same thread that calls event methods also calls `paint()`.

■ **Note** All event-driven user-interface toolkits have this idea of a system-owned user-interface thread. In AWT and Swing, it's called the `event dispatch thread`. The same rule applies: if you're running inside a thread that doesn't belong to you, don't take all day about it.

Methods that are called by a thread that doesn't belong to you are callbacks. The rule of thumb for callbacks is that you shouldn't do anything that takes a long time. Since the thread doesn't belong to you, you shouldn't hold it up a long time performing your work. Because this

thread is responsible for operating the user interface, holding it up with lengthy computations will make your application look lobotomized. Suppose, for example, that you had to retrieve some data from the network. In response to a command, you might do something like this:

```
public void commandAction(Command c, Displayable s) {
  if (c == mNetworkCommand) {
    // Create a progress screen, progressScreen.
    mDisplay.setCurrent(progressForm);
    // Now do the network stuff.
    // Oops! Users never see progressScreen.
  }
  // ...
}
```

The problem is that the progress screen won't be shown. The `commandAction()` method is called from the user-interface thread, the same thread that's responsible for painting the screen. If you tie up this thread with some lengthy processing of your own, the user-interface thread never has a chance to update the screen. If you need to do something that takes a long time, create a separate thread for it. In the `Jargoneer` example in Chapter 2, for example, network access was performed in a separate thread.

In certain situations, you will need to ask the user-interface thread to execute code on your behalf. If you are showing an animation, for example, you'll want to make sure that the frames of the animation are properly synchronized with the repainting cycle. Otherwise, you're likely to end up showing frames that are partially drawn.

`Display` has a mechanism for executing your code in the user-interface thread. It has a method, `callSerially()`, that accepts a `Runnable`. When the user-interface thread is ready, meaning when it has finished servicing all repaint requests, it will execute the `run()` method of the `Runnable` from the user-interface thread. A typical animation, then, looks like this:

```
public class AnimationCanvas
    extends Canvas
    implements Runnable {
  public start() {
    run();
  }

public void paint(Graphics g) {
    // Paint a frame of the animation.
  }

  public void run() {
    // Update our state.
    // Now request a paint of the new frame.
    repaint();
    Display.callSerially(this);
  }
}
```

You'd kick off the animation by calling `start()`, which in turn would simply call `run()`. Inside `run()`, you update your state and call `repaint()` to request the painting of a new frame. Then you use `callSerially()` to request that you get called again when the painting is done.

This technique results in an animation that runs as fast as the device allows. Many applications, however, need to provide a consistent experience across different devices. In these cases, it makes much more sense to use a separate animation thread with a consistent frame delay. The following example demonstrates this technique. It consists of two classes, `Sweep` and `SweepCanvas`. `Sweep` is a MIDlet that displays the class that actually implements the animation, `SweepCanvas`. The running `SweepCanvas` is shown in Figure 13-9.

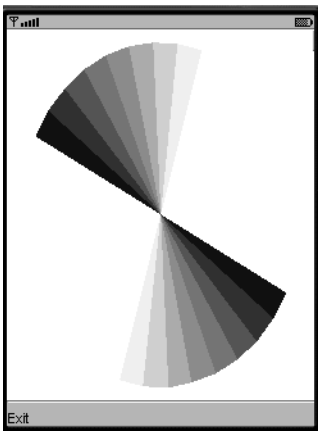


Figure 13-9. *SweepCanvas animation running on the WTK default emulator*

First, here's the source code for `Sweep`:

```
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;

public class Sweep
    extends MIDlet {
  public void startApp() {
    final SweepCanvas sweeper = new SweepCanvas();
    sweeper.start();

    sweeper.addCommand(new Command("Exit", Command.EXIT, 0));
    sweeper.setCommandListener(new CommandListener() {
      public void commandAction(Command c, Displayable s) {
        sweeper.stop();
        notifyDestroyed();
      }
    });
```

```
    Display.getDisplay(this).setCurrent(sweeper);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}
}
```

And here's the code for `SweepCanvas`:

```
import javax.microedition.lcdui.*;

public class SweepCanvas
    extends Canvas
    implements Runnable {
  private boolean mTrucking;
  private int mTheta;
  private int mBorder;
  private int mDelay;

  public SweepCanvas() {
    mTheta = 0;
    mBorder = 10;
    mDelay = 50;
  }

  public void start() {
    mTrucking = true;
    Thread t = new Thread(this);
    t.start();
  }

  public void stop() {
    mTrucking = false;
  }

  public void paint(Graphics g) {
    int width = getWidth();
    int height = getHeight();

    // Clear the Canvas.
    g.setGrayScale(255);
    g.fillRect(0, 0, width - 1, height - 1);
```

```
    int x = mBorder;
    int y = mBorder;
    int w = width - mBorder * 2;
    int h = height - mBorder * 2;
    for (int i = 0; i < 8; i++) {
      g.setGrayScale((8 - i) * 32 - 16);
      g.fillArc(x, y, w, h, mTheta + i * 10, 10);
      g.fillArc(x, y, w, h, (mTheta + 180) % 360 + i * 10, 10);
    }
  }

  public void run() {
    while (mTrucking) {
      mTheta = (mTheta + 1) % 360;
      repaint();
      try { Thread.sleep(mDelay); }
      catch (InterruptedException ie) {}
    }
  }
}
```

The Game API offers another option for running an animation. In the next chapter, you'll see how `Sweep`'s simple animation can be implemented using `GameCanvas`.

Summary

We've covered a lot of ground in this chapter. The `Canvas` class provides a low-level interface for games or other demanding applications. You can draw shapes, text, and images on a `Canvas` using the `Graphics` class. Furthermore, you can receive detailed input information about key and pointer events. Game actions are simple generalized input methods based on key events. Finally, you should understand the multithreading issues with repainting and event callbacks. Lengthy processing should be placed in a separate thread so that it doesn't bring the system-owned user-interface thread to a grinding halt. Animations can use `Display`'s `callSerially()` method to synchronize with the user-interface thread, although more commonly they will be implemented using a separate animation thread. The next chapter details the Game API.

CHAPTER 14

The Game API

MIDP is an attractive platform for games, the leading edge of consumer J2ME software. In the next chapter, you'll read about the exciting new 3D graphics capabilities available, and in Chapter 16 you will read about MIDP's support for multimedia. This chapter describes the Game API, which simplifies writing 2D games.

Overview

The Game API builds on the `Canvas` and `Graphics` classes you read about in Chapter 13. The entire API is composed of five classes in the `javax.microedition.lcdui.game` package. One class, `GameCanvas`, provides methods for animation and key polling. The other four classes deal with layers, which can be used to compose scenes from several different elements.

`GameCanvas` offers two main advantages over `Canvas`. First, your application has control over exactly *when* the display is updated, instead of having to wait for the system software to call `paint()`. Second, you can control what region of the screen is updated. `GameCanvas` gives your application very specific control of display updates.

Driving Animation with GameCanvas

`GameCanvas` extends `javax.microedition.lcdui.Canvas` with methods for animation and key state polling. `GameCanvas` is used differently from `Canvas`:

- To use `Canvas`, you subclass it and define the `paint()` method. Inside `paint()`, you use `Graphics` to render graphics on the screen. When you change something and want to update the screen, you call `repaint()`, and the system calls `paint()` again for you.
- To use `GameCanvas`, you subclass it. To draw on the screen, you use the `Graphics` returned from `getGraphics()`. When you want updates to appear on the screen, call `flushGraphics()`, which does not return until the screen is updated. For more specific updates, use the method `flushGraphics(int x, int y, int width, int height)`, which only updates a region of the screen.

```
public void flushGraphics(int x, int y, int width, int height)
```

`GameCanvas`'s model of use makes it easy to use inside a game loop like this:

```
Graphics g = getGraphics();
while(true) {
  // Check for user input.
  // Update game state.
  // Draw stuff using g.
  flushGraphics();
}
```

To subclass GameCanvas, you need to call its protected constructor from your subclass's constructor. This constructor accepts a single boolean argument, which indicates whether the normal key event mechanism should be suppressed for the GameCanvas instance. The normal key event mechanism refers to the callback mechanism of keyPressed(), keyReleased(), and keyRepeated(). Suppressing the normal mechanism may result in better performance. GameCanvas provides an alternative method for responding to key events, which is detailed in the next section.

To show how GameCanvas works for drawing, we'll rewrite the SweepCanvas example from Chapter 13 using GameCanvas (see Listing 14-1). Note that the subclass no longer overrides paint(). All the action happens in run(), which is executed in a separate thread that drives the animation. The run() method calls render(), which does the actual drawing (and is identical to the old paint()).

Listing 14-1. *Using GameCanvas for Animation*

```
import javax.microedition.lcdui.*;
import javax.microedition.lcdui.game.*;

public class SweepGameCanvas
    extends GameCanvas
    implements Runnable {
  private boolean mTrucking;
  private int mTheta;
  private int mBorder;
  private int mDelay;

  public SweepGameCanvas() {
    super(true);
    mTheta = 0;
    mBorder = 10;
    mDelay = 50;
  }

  public void start() {
    mTrucking = true;
    Thread t = new Thread(this);
    t.start();
  }
```

```
  public void stop() {
    mTrucking = false;
  }

  public void render(Graphics g) {
    int width = getWidth();
    int height = getHeight();

    // Clear the Canvas.
    g.setGrayScale(255);
    g.fillRect(0, 0, width - 1, height - 1);

    int x = mBorder;
    int y = mBorder;
    int w = width - mBorder * 2;
    int h = height - mBorder * 2;
    for (int i = 0; i < 8; i++) {
      g.setGrayScale((8 - i) * 32 - 16);
      g.fillArc(x, y, w, h, mTheta + i * 10, 10);
      g.fillArc(x, y, w, h, (mTheta + 180) % 360 + i * 10, 10);
    }
  }

  public void run() {
    Graphics g = getGraphics();
    while (mTrucking) {
      mTheta = (mTheta + 1) % 360;
      render(g);
      flushGraphics();
      try { Thread.sleep(mDelay); }
      catch (InterruptedException ie) {}
    }
  }
}
```

We'll assume you can write your own MIDlet to display `SweepGameCanvas`. If you've downloaded the examples, `SweepGame` is a MIDlet that displays `SweepGameCanvas`.

Polling for Key States

`GameCanvas` offers an alternative method for responding to key presses, which are expected to be the way the user controls the game. Instead of passively waiting for the key event callbacks defined in `Canvas`, `GameCanvas` offers a method that returns the current state of the keys:

```
public int getKeyStates()
```

This is attractive for games because it gives your application more control. Instead of waiting for the system to invoke the key callback methods in `Canvas`, you can immediately find out the state of the device keys.

The returned integer uses one bit to represent each of the nine game actions. A one bit indicates a key press, while a zero bit indicates no key press. Each of the bits is represented by a constant in the `GameCanvas` class as shown in Table 14-1.

Table 14-1. *Game Action Bit Constants in GameCanvas*

GameCanvas Bit Constants	Corresponding GameCanvas Action Constants
UP_PRESSED	UP
DOWN_PRESSED	DOWN
LEFT_PRESSED	LEFT
RIGHT_PRESSED	RIGHT
FIRE_PRESSED	FIRE
GAME_A_PRESSED	GAME_A
GAME_B_PRESSED	GAME_B
GAME_C_PRESSED	GAME_C
GAME_D_PRESSED	GAME_D

By grabbing the current state of the keys (a technique called *polling*), you can respond to user actions within the game loop instead of relying on the event callback methods, which run in a different thread. You could expand the example `GameCanvas` loop presented earlier as follows to respond to key presses:

```
Graphics g = getGraphics();
while(true) {
  // Check for user input.
  int ks = getKeyStates();
  if ((ks & UP_PRESSED) != 0)
    moveUp();
  else if ((ks & DOWN_PRESSED) != 0)
    moveDown();
  // ...

  // Update game state.
  // Draw stuff using g.
  flushGraphics();
}
```

If you're still paying attention, you're probably wondering what happens when the user presses and releases a key between the times when your application calls `getKeyStates()`. The key states are *latched*, which means that a key press sets the corresponding bit and makes it

stick until the next call to `getKeyStates()`. Every time you call `getKeyStates()`, the latched values are all cleared.

Understanding Layers

The rest of the Game API is devoted to *layers*. Layers are graphic elements that can be combined to create a complete scene. You might, for example, have a background of mountains, another background of city buildings, and several smaller items in the foreground: people, spaceships, cars, whatever.

The technique of combining layers resembles traditional hand-drawn animations. Background and foreground images are drawn on transparent cels, which are placed one on top of another and photographed to create the final scene.

In the Game API, an instance of the `javax.microedition.lcdui.game.Layer` class represents a layer. `Layer` is abstract, with two concrete subclasses. `Layer` itself is pretty straightforward. It has a location, a size, and can be visible or invisible. The location and size are accessed and modified with the following methods, which are self-explanatory:

```
public final int getX()
public final int getY()
public final int getWidth()
public final int getHeight()
public void setPosition(int x, int y)
```

`Layer` also offers a handy method for moving relative to the current position. Pass pixel offsets to the following method to adjust the position of the layer:

```
public void move(int dx, int dy)
```

The layer's visibility is accessed using `getVisible()` and `setVisible()`.

The last method in `Layer` is `paint()`, which is declared abstract. Subclasses override this method to define their appearance.

Managing Layers

Before we tell you about `Layer`'s concrete children, we'll explain how layers are put together to form a complete scene. You could do it yourself, maintaining a list of layers and drawing each of them using their `paint()` methods. Fortunately, the Game API includes `LayerManager`, a class that handles most of the details for you. To create a `LayerManager`, just call its no-argument constructor.

Most of `LayerManager`'s job is keeping an ordered list of layers. Layers have an index, which indicates their position front to back. A position of 0 is on top, closest to the user, while larger indices are farther away, towards the bottom. (The order of layers is sometimes called the *z order*.)

Layers may be added to the bottom of the list using this method:

```
public void append(Layer l)
```

You can add a layer at a specific location using `insert()`:

```
public void insert(Layer l, int index)
```

For example, you could add a layer to the top of the list by inserting a layer at index 0.

You can find the number of layers in the `LayerManager` by calling `getSize()`. If you'd like to retrieve the layer at a certain position, pass the index to the `getLayerAt()` method.

Finally, you can remove a layer by passing the `Layer` object to the `remove()` method.

`LayerManager` includes the concept of a *view window*, which is the rectangular portion of the scene that will be drawn. The assumption is that the overall scene is larger than the screen of the device, so only a portion will be drawn at any time. By default, the view window has its origin at `0, 0` and is as large as it can be (`Integer.MAX_VALUE` for both width and height). You can set the view window using the following method, where the `x` and `y` coordinates are relative to the origin of the `LayerManager`.

```
public void setViewWindow(int x, int y, int width, int height)
```

To actually draw the scene represented by the `LayerManager`'s layers, call the `paint()` method:

```
public void paint(Graphics g, int x, int y)
```

The view window of the scene will be drawn using the given `Graphics` at the specified location, which is specified in the coordinate system of the `Graphics`.

If you're still fuzzy on the relationship between a layer manager, its layers, and its view window, see the API documentation for `LayerManager`, which contains two very helpful figures.

Using Tiled Layers

A tiled layer is made from a palette of tiles, just as you might assemble decorative tiles to create a pretty design next to your bathtub. The tiles come from a single image that is divided into equal-sized pieces.

A `TiledLayer` is drawn on a `Graphics` object using the `paint()` method inherited from `Layer`. Like any other `Layer`, a tiled layer renders itself at its current location in the coordinate system of the `Graphics`. Furthermore, like any other `Layer`, a tiled layer can be part of a `LayerManager` and can be rendered automatically when the `LayerManager` is rendered using *its* `paint()` method.

For example, Figure 14-1 is 240 pixels wide and 96 pixels high.

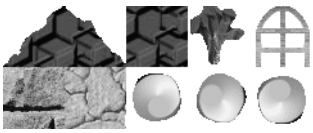


Figure 14-1. *A source image for a tiled layer*

The image can be divided into 10 square tiles, each with a width and height of 48 pixels. Tiles are numbered as shown in Figure 14-2.

1	2	3	4	5
6	7	8	9	10

Figure 14-2. *Tile numbering*

The image could have been laid out several different ways to achieve the same result. Two of the other possibilities are shown in Figure 14-3.

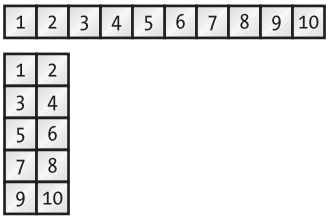


Figure 14-3. *Other tile image layouts*

Note that tile indices are numbered starting at one, while row and column numbers start at zero.

The tiled layer itself is a grid of *cells*, where each cell is occupied by one tile. You specify the number of rows and columns in the tiled layer at construction. The exact size of a tiled layer is as follows:

```
width = [number of columns] x [tile width]
height = [number of rows] x [tile height]
```

Creating and Initializing a TiledLayer

To create a `TiledLayer`, supply the number of columns and rows, the source image, and the tile dimensions to the constructor:

```
public TiledLayer(int columns, int rows,
    Image image, int tileWidth, int tileHeight)
```

The image and tile dimensions describe a *static tile set*. You can change the static tile set on an existing `TiledLayer` with the following method:

```
public void setStaticTileSet(Image image, int tileWidth, int tileHeight)
```

The number of columns and rows in a `TiledLayer` can be retrieved with `getColumns()` and `getRows()`. To retrieve the tile dimensions, use `getCellWidth()` and `getCellHeight()`. (Although the method naming isn't quite consistent, this works because the pixel size of each cell is the same as the pixel size of the tiles.)

A `TiledLayer` is empty when you first create it. To assign a tile to a cell, use this method:

```
public void setCell(int col, int row, int tileIndex)
```

All the cells in the `TiledLayer` are initially filled with tile index 0, which indicates a blank tile. You can retrieve the tile index of a particular cell by passing its column and row number to `getCell()`. If you would like to assign the same tile to a range of cells, use the `fillCells()` method:

```
public void fillCells(int col, int row, int numCols, int numRows,
    int tileIndex)
```

The `col`, `row`, `numCols`, and `numRows` parameters describe a rectangular region of cells that will be filled with the specified tile. For example, `fillCells(2, 0, 1, 2, 6)` would assign tile 6 to the cells in the first and second rows of the third column of the tiled layer.

The following excerpt (adapted from `QuatschCanvas.java` in the source code) demonstrates one way to create and initialize a `TiledLayer`:

```
Image backgroundImage = Image.createImage("/background_tiles.png");
TiledLayer background = new TiledLayer(8, 4, backgroundImage, 48, 48);
background.setPosition(12, 0);
int[] map = {
  1, 2, 0, 0, 0, 0, 0, 0,
  3, 3, 2, 0, 0, 0, 5, 0,
  3, 3, 3, 2, 4, 1, 3, 2,
  6, 6, 6, 6, 6, 6, 6, 6
};
for (int i = 0; i < map.length; i++) {
  int column = i % 8;
  int row = (i - column) / 8;
  background.setCell(column, row, map[i]);
}
```

Using the source image of Figure 14-1, this code produces the tiled layer shown in Figure 14-4.

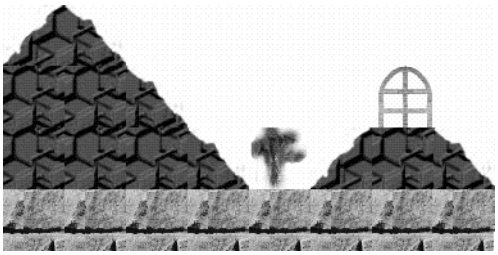


Figure 14-4. *A tiled layer*

You now know almost everything there is to know about `TiledLayer`; it serves as a simple map between a palette of tiles and a fully assembled layer.

Using Animated Tiles

There is one additional twist: *animated* tiles. An animated tile is a virtual tile whose mapping can be changed at runtime. Although you could accomplish the same thing by calling `setCell()` on all the cells you wanted to change, using an animated tile allows you to make a single call that changes all the affected cells.

To use an animated tile, you create one by calling this method:

```
public int createAnimatedTile(int staticTileIndex)
```

You pass a regular tile index to the method, which is the initial tile that should be used for the animated tile. The method returns a special animated tile index. (There's no magic here; it's just a negative number.)

To assign an animated tile to a cell, pass the return value from `createAnimatedTile()` to `setCell()`. When you want to change the contents of an animated tile, use the following method:

```
public void setAnimatedTile(int animatedTileIndex, int staticTileIndex)
```

This assigns the supplied tile index to the animated tile. All cells that have the supplied animated tile will now display the given tile.

If you need to retrieve the current tile associated with an animated tile, just pass the animated tile index to `getAnimatedTile()`.

Using Sprites

While a `TiledLayer` uses a palette of tiles to fill a large area, a `Sprite` uses a palette of tiles to animate a layer that is the same size as a single tile. Usually a `Sprite` represents one of the protagonists in a game. In `Sprite` parlance, tiles are called *frames* instead. As with a `TiledLayer`, a `Sprite` is created from a source image that is divided into equally sized frames.

```
public Sprite(Image image, int frameWidth, int frameHeight)
```

There's also a special case—if the image contains just one frame, it will not be animated:

```
public Sprite(Image image)
```

Interestingly, a `Sprite` cannot be created from separate frame images; the frames must be packed into a single source image (this packing is better for compression).

If you want to change the source image after the `Sprite` is created, use `setImage()`:

```
public void setImage(Image img, int frameWidth, int frameHeight)
```

The total number of frames contained in the `Sprite` is returned from `getRawFrameCount()`.

Like any other `Layer`, Sprites are rendered when the `paint()` method is called. Usually the `Sprite` will belong to a `LayerManager`, in which case it is rendered automatically when the `LayerManager` is rendered.

Animating Sprites

Sprite animation is all about *frame sequences*. When a `Sprite` is created, it has a default frame sequence that includes every frame in the source image. For example, consider the source image for a fictional character named Dr. Quatsch, shown in Figure 14-5.

Figure 14-5. *A sprite source image*

This image is 192×48 pixels. If it is created with a 48×48-pixel frame size, there are four frames. The default frame sequence is `{ 0, 1, 2, 3 }`. Note that frame indices are numbered starting at zero, while tile indices (in the `TiledLayer` class) are numbered starting at one.

In Figure 14-5, the first three frames represent Dr. Quatsch running, while the fourth is a frame that shows him standing still. The following method changes the current frame sequence:

```
public void setFrameSequence(int[] sequence)
```

For example, the following code shows how you could create a new `Sprite` and set its frame sequence to include only the running frames:

```
int[] runningSequence = { 0, 1, 2 };
Image quatschImage = Image.createImage("/quatsch.png");
Sprite quatsch = new Sprite(quatschImage, 48, 48);
quatsch.setFrameSequence(runningSequence);
```

`Sprite` provides several methods for navigating through the frame sequence. The animation doesn't happen automatically; your application needs to tell the `Sprite` when it's time to move to the next frame in the sequence. Usually this is accomplished in a separate thread, most likely as part of the animation thread. To move forward and backward in the sequence, use `nextFrame()` and `prevFrame()`. These methods do what you'd expect at the ends of the sequence, wrapping around to the next value. For example, using the frame sequence of `{ 0, 1, 2 }`, if the `Sprite`'s current frame is `2` and you call `nextFrame()`, the current frame will be set to `0`.

You can jump directly to a particular frame using this method:

```
public void setFrame(int sequenceIndex)
```

Note that this method accepts a sequence index. If the `Sprite`'s frame sequence is `{ 2, 3, 1, 9 }`, then calling `setFrame(1)` would result in the `Sprite`'s current frame being set to `3`.

Nothing happens visually when you adjust the `Sprite`'s current frame. Changes will only be visible the next time the `Sprite` is rendered using its `paint()` method. Typically, this will be at the end of your animation loop if you are using `GameCanvas`.

To find out the current frame sequence index, call `getFrame()`. Don't get confused here; the method does not return a frame index, but the current index in the current frame sequence. Interestingly, there is no `getFrameSequence()` method, so if you haven't saved the current frame sequence, there's no way to find out the current frame index. You can, however, retrieve the number of elements in the current frame sequence using `getFrameSequenceLength()`.

Transforming Sprites

You may have noticed that the frames shown in Figure 14-5 only show Dr. Quatsch facing left. What if he's going to run to the right? `Sprite` includes support for *transformations* so that you can use the API to generate additional frames that are simple transformations of existing frames. This approach reduces the total number of stored images, effectively reducing resource (disk space, memory, etc.) usage. The following method applies a transformation to a `Sprite`:

```
public void setTransform(int transform)
```

The `transform` argument can be any of the constant values defined in the `Sprite` class:

```
TRANS_NONE
TRANS_ROT90
TRANS_ROT180
TRANS_ROT270
TRANS_MIRROR
TRANS_MIRROR_ROT90
TRANS_MIRROR_ROT180
TRANS_MIRROR_ROT270
```

To make Dr. Quatsch face right instead of left, you would apply a `TRANS_MIRROR` transformation. To understand all the transformations, see the `Sprite` API documentation, which contains a set of fighter plane images that are very helpful.

The only tricky part about transformations is the *reference pixel*. All `Sprites` have a reference pixel, which is expressed in the `Sprite`'s own coordinate space; by default, the reference pixel is located at `0, 0`, the upper-left corner of the `Sprite`. When the `Sprite` is transformed, the reference pixel is also transformed.

When a transformation is applied, the `Sprite`'s position is changed so that the current location of the reference pixel does not change, even after it is transformed. For example, Figure 14-6 shows how the position of the `Sprite` changes when a simple `TRANS_MIRROR` transformation is applied.

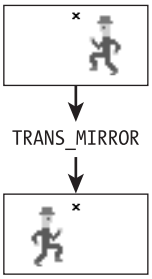


Figure 14-6. *The reference pixel doesn't move.*

Suppose, for example, that the original position of the `Sprite` was `100, 100` (in the coordinate system of the container), and the reference pixel position was `0, 0` (in the coordinate system of the `Sprite`). After applying a `TRANS_MIRROR` rotation, the `Sprite`'s position is adjusted so that the transformed reference pixel is in the same location as the original reference pixel. Because the frame width is 48 pixels, the `Sprite`'s position (its upper-left corner) changes from `100, 100` to `52, 100`.

To adjust the location of the reference point in the `Sprite`'s untransformed coordinate system, use this method:

```
public void defineReferencePixel(int x, int y)
```

In the case of Dr. Quatsch, we want to apply a mirror transformation without having the `Sprite` move, so we set the reference pixel to be at the center of the 48×48 frame:

```
// Sprite quatsch is defined as before.
quatsch.defineReferencePixel(24, 24);
```

To find the current location of the Sprite's reference pixel in its containing coordinate system, use getRefPixelX() and getRefPixelY(). Don't get confused: defineReferencePixel() accepts coordinates relative to the Sprite's origin, while getRefPixelX() and getRefPixelY() return values relative to the Sprite's container. It's also possible to set the position of the Sprite based on its reference point. You already know you can set the position of the Sprite's upper-left corner using the setPosition() method that is inherited from Layer, but the following method sets the current position of the Sprite's reference point:

```
public void setRefPointPosition(int x, int y)
```

This is more convenient than it might appear at first, as it allows you to place the reference point at a specific position, regardless of the current transformation.

Handling Collisions

Sprite provides methods to answer critical questions that come up in games—did the bullet hit the spaceship? Is Dr. Quatsch standing in front of the door?

The Game API supports two techniques for collision detection:

1. The implementation can compare rectangles representing a sprite and another sprite. A collision has occurred if the rectangles intersect. This is a quick way to test for collisions, but it may produce inaccurate results for nonrectangular shapes.

2. The implementation can compare each pixel of the sprite and another sprite. If an opaque pixel in the sprite overlaps an opaque pixel in the other sprite, a collision has occurred. This technique involves more computation but produces a more accurate result.

A Sprite has a *collision rectangle* that is used for collision detection. It is defined in the coordinate system of the Sprite itself, like the reference pixel. By default, the collision rectangle is located at 0, 0 and is the same width and height as the Sprite. You can change the collision rectangle using this method:

```
public void defineCollisionRectangle(int x, int y, int width, int height);
```

The collision rectangle serves two purposes. If pixel-level collision detection is not used, the collision rectangle is used to determine collisions. If pixel-level collision detection is used, then only pixels inside the collision rectangle are examined.

Sprite is capable of detecting collisions with other Sprites, TiledLayers, and Images.

```
public final boolean collidesWith(Sprite s, boolean pixelLevel)
public final boolean collidesWith(TiledLayer t, boolean pixelLevel)
public final boolean collidesWith(Image image,
    int x, int y, boolean pixelLevel)
```

The semantics of each method are subtly different, as described in Table 14-2.

Table 14-2. *Collision Detection with Sprite*

Target	Intersecting Rectangle	Pixel Level
`Sprite`	Compares collision rectangles	Compares pixels inside the collision rectangles
`TiledLayer`	Compares the `Sprite`'s collision rectangle and tiles in the `TiledLayer`	Compares pixels inside the `Sprite`'s collision rectangle with pixels in the `TiledLayer`
`Image`	Compares the `Sprite`'s collision rectangle and the `Image`'s bounds	Compares pixels inside the `Sprite`'s collision rectangle with pixels in the `Image`

Copying Sprites

`Sprite` includes a copy constructor:

```
public Sprite(Sprite s)
```

This is more powerful than you might think. It creates a new `Sprite` with all of the attributes of the original, including

- Source image frames
- Frame sequence
- Current frame
- Current transformation
- Reference pixel
- Collision rectangle

Putting It All Together

`QuatschCanvas`, shown in Listing 14-2, is an example that showcases many of the features of the Game API. Although it looks long, it's broken into manageable methods and demonstrates quite a few features of the Game API:

- Using an animation loop in `GameCanvas`
- Polling for key state using `GameCanvas`
- Using a `LayerManager` to maintain multiple layers
- Creating a `Sprite` and `TiledLayers`
- Animating a `Sprite`, including changing frame sequences and transformations
- Using an animated tile in a `TiledLayer`

A corresponding MIDlet, `QuatschMIDlet`, is available in the code download but not presented here. It creates and displays a `QuatschCanvas` and provides commands for showing and hiding the layers.

Figure 14-7 shows `QuatschMIDlet` running in the emulator.

Figure 14-7. *The whole iguana: sprites and tiled layers*

Listing 14-2 contains the source code for `QuatschCanvas`.

Listing 14-2. *QuatschCanvas, a Game API Example*

```
import java.io.IOException;

import javax.microedition.lcdui.*;
import javax.microedition.lcdui.game.*;

public class QuatschCanvas
    extends GameCanvas
    implements Runnable {
  private boolean mTrucking;

  private LayerManager mLayerManager;

  private TiledLayer mAtmosphere;
  private TiledLayer mBackground;
  private int mAnimatedIndex;

  private Sprite mQuatsch;
  private int mState, mDirection;

  private static final int kStanding = 1;
  private static final int kRunning = 2;
```

```
private static final int kLeft = 1;
private static final int kRight = 2;

private static final int[] kRunningSequence = { 0, 1, 2 };
private static final int[] kStandingSequence = { 3 };

public QuatschCanvas(String quatschImageName,
    String atmosphereImageName, String backgroundImageName)
    throws IOException {
  super(true);

  // Create a LayerManager.
  mLayerManager = new LayerManager();
  int w = getWidth();
  int h = getHeight();
  mLayerManager.setViewWindow(96, 0, w, h);

  createBackground(backgroundImageName);
  createAtmosphere(atmosphereImageName);
  createQuatsch(quatschImageName);
}

private void createBackground(String backgroundImageName)
    throws IOException {
  // Create the tiled layer.
  Image backgroundImage = Image.createImage(backgroundImageName);
  int[] map = {
    0, 0, 0, 0, 0, 0, 0, 0,
    0, 0, 0, 0, 0, 0, 0, 0,
    1, 2, 0, 0, 0, 0, 0, 0,
    3, 3, 2, 0, 0, 0, 5, 0,
    3, 3, 3, 2, 4, 1, 3, 2,
    6, 6, 6, 6, 6, 6, 6, 6
  };
  mBackground = new TiledLayer(8,6, backgroundImage, 48, 48);
  mBackground.setPosition(12, 0);
  for (int i = 0; i < map.length; i++) {
    int column = i % 8;
    int row = (i - column) / 8;
    mBackground.setCell(column, row, map[i]);
  }
  mAnimatedIndex = mBackground.createAnimatedTile(8);
  mBackground.setCell(3, 0, mAnimatedIndex);
  mBackground.setCell(5, 0, mAnimatedIndex);
  mLayerManager.append(mBackground);
}
```

```
private void createAtmosphere(String atmosphereImageName)
    throws IOException {
  // Create the atmosphere layer.
  Image atmosphereImage = Image.createImage(atmosphereImageName);
  mAtmosphere = new TiledLayer(8, 1, atmosphereImage,
      atmosphereImage.getWidth(), atmosphereImage.getHeight());
  mAtmosphere.fillCells(0, 0, 8, 1, 1);
  mAtmosphere.setPosition(0, 192);
  mLayerManager.insert(mAtmosphere, 0);
}

private void createQuatsch(String quatschImageName)
    throws IOException {

  // Create the sprite.
  Image quatschImage = Image.createImage(quatschImageName);
  mQuatsch = new Sprite(quatschImage, 48, 48);
  mQuatsch.setPosition(96 + (getWidth() - 48) / 2, 192);
  mQuatsch.defineReferencePixel(24, 24);
  setDirection(kLeft);
  setState(kStanding);
  mLayerManager.insert(mQuatsch, 1);
}

public void start() {
  mTrucking = true;
  Thread t = new Thread(this);
  t.start();
}

public void run() {
  int w = getWidth();
  int h = getHeight();
  Graphics g = getGraphics();
  int frameCount = 0;
  int factor = 2;
  int animatedDelta = 0;

  while (mTrucking) {
    if (isShown()) {
      int keyStates = getKeyStates();
      if ((keyStates & LEFT_PRESSED) != 0) {
        setDirection(kLeft);
        setState(kRunning);
        mBackground.move(3, 0);
        mAtmosphere.move(3, 0);
        mQuatsch.nextFrame();
      }
```

```
      else if ((keyStates & RIGHT_PRESSED) != 0) {
        setDirection(kRight);
        setState(kRunning);
        mBackground.move(-3, 0);
        mAtmosphere.move(-3, 0);
        mQuatsch.nextFrame();
      }
      else {
        setState(kStanding);
      }

      frameCount++;
      if (frameCount % factor == 0) {
        int delta = 1;
        if (frameCount / factor < 10) delta = -1;
        mAtmosphere.move(delta, 0);
        if (frameCount / factor == 20) frameCount = 0;

        mBackground.setAnimatedTile(mAnimatedIndex,
            8 + animatedDelta++);
        if (animatedDelta == 3) animatedDelta = 0;
      }

      g.setColor(0x5b1793);
      g.fillRect(0, 0, w, h);

      mLayerManager.paint(g, 0, 0);

      flushGraphics();
    }

    try { Thread.sleep(80); }
    catch (InterruptedException ie) {}
  }
}

public void stop() {
  mTrucking = false;
}

public void setVisible(int layerIndex, boolean show) {
  Layer layer = mLayerManager.getLayerAt(layerIndex);
  layer.setVisible(show);
}
```

```
  public boolean isVisible(int layerIndex) {
    Layer layer = mLayerManager.getLayerAt(layerIndex);
    return layer.isVisible();
  }


  private void setDirection(int newDirection) {
    if (newDirection == mDirection) return;
    if (mDirection == kLeft)
      mQuatsch.setTransform(Sprite.TRANS_MIRROR);
    else if (mDirection == kRight)
      mQuatsch.setTransform(Sprite.TRANS_NONE);
    mDirection = newDirection;
  }

  private void setState(int newState) {
    if (newState == mState) return;
    switch (newState) {
      case kStanding:
        mQuatsch.setFrameSequence(kStandingSequence);
        mQuatsch.setFrame(0);
        break;
      case kRunning:
        mQuatsch.setFrameSequence(kRunningSequence);
        break;
      default:
        break;
    }
    mState = newState;
  }
}
```

Special Effects

Although they are not strictly contained in the Game API, two other methods in the `Display` class are closely related:

```
public boolean flashBacklight(int duration)
public boolean vibrate(int duration)
```

Both methods accept a `duration` in milliseconds that specifies how long the backlight should be turned on or how long the device should vibrate. Both methods return `true` to indicate success or `false` if the device does not support a backlight or vibration (or if your application is not running in the foreground).

Summary

This chapter described the Game API, a set of classes that simplify developing two-dimensional games. The `GameCanvas` class provides a drawing surface that can easily be rendered in a game thread. `GameCanvas` also provides key state polling, useful for detecting user input in a game thread. The remainder of the Game API is based on layers, which are elements that can be combined to create complex scenes. `LayerManager` makes it easy to maintain multiple layers. The `Sprite` class supports animation and collision detection. Large scenes or backgrounds can be constructed efficiently using `TiledLayer`. Finally, `Display` includes methods for controlling the backlight and vibration of a device. Game developers have a lot to be happy about. Read on to the next chapter and discover how to add 3D graphics to your MIDP applications and games.

CHAPTER 15

3D Graphics

The ability to use mobile communication devices to communicate via moving video images and interactive 3D graphics has long been a topic in science fiction and Hollywood movies. MIDP and MMAPI make video a reality. This chapter looks at JSR 184, the optional API for the rendering of 3D graphics.

Overview

A 3D graphics API is a prerequisite for easily developing 3D games. While 3D games are new to mobile devices such as cell phones, they are a staple and a growing market segment for desktop PCs. Many other applications for 3D graphics exist besides games, such as animated characters in user interfaces, architectural prototypes, and data visualization.

The Mobile 3D Graphics API, often called M3G, is an optional API that facilitates the display and manipulation of 3D graphics elements on mobile information devices. The M3G API 1.0 is fully specified in JSR 184; you can access this document here:

```
http://www.jcp.org/en/jsr/detail?id=184
```

Working with 3D graphics typically requires the computation of coordinates in floating point. Because of this, M3G can only be implemented on top of CLDC 1.1. CLDC 1.0 does not include floating-point support. To render 3D graphics onto the screen, M3G must be integrated with the user interface libraries on a device. This means that M3G will work well with familiar MIDP components such as `Canvas`, `CustomItem`, and `GameCanvas`.

Note Even though M3G requires CLDC 1.1's floating-point support, the API still attempts to use faster integer math wherever possible in order to work well on small devices that may not have floating-point hardware.

The actual M3G "3D engine" is usually implemented with the help of native libraries on the device. In many cases, it can be implemented on top of OpenGL ES. OpenGL has long been a robust and popular API for 3D rendering on workstations and PCs. OpenGL ES is the little cousin of OpenGL, a subset, and is becoming the de facto standard native 3D API for embedded devices. OpenGL ES is often found in game systems and other visual devices. Its popularity has

made it a viable choice for mobile device vendors to include in their devices. The pairing of M3G with OpenGL ES is ideal since it greatly facilitates the implementation of M3G for mobile device vendors, allowing them to adopt 3D graphics with less effort (and cost). More information on OpenGL ES can be located at

```
http://www.khronos.org/opengles/
```

Figure 15-1 depicts the relationship between M3G, MIDP, OpenGL ES, and CLDC.

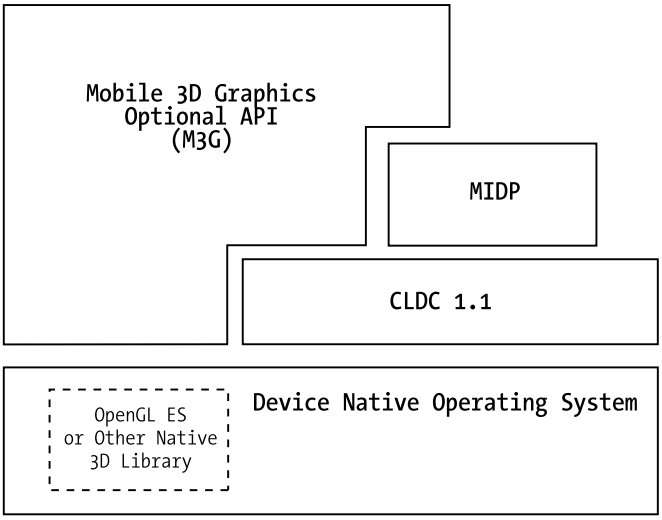


Figure 15-1. *M3G, MIDP, CLDC, and OpenGL ES relationship*

In Figure 15-1, you can see the dependence of M3G on CLDC, MIDP, and potentially a native 3D implementation such as Open GL ES.

Rendering 3D Graphics

The `javax.microedition.m3g` package contains all the 3D API classes.

Similar to the 2D `Graphics` context class that you get within the `paint()` method of a `Canvas`, you will need an instance of the `Graphics3D` class to render 3D graphics. `Graphics3D` is a singleton. You can obtain the one and only instance using this factory method:

```
static Graphics3D  getInstance();
```

To render a single frame of 3D graphics, you need to follow these steps:

1. Obtain the `Graphics3D` instance.
2. Obtain a 2D `Graphics` instance (from `Canvas`, `GameCanvas`, etc.), which will be used to display the frame.
3. Bind the `Graphics3D` instance to the 2D `Graphics` instance; the frame of the 3D image will be drawn onto the 2D context.

4. Use the M3G API to set up and update the 3D scene.
5. Call one of the `render()` methods of `Graphics3D` to render a frame of the 3D scene.
6. Call the `Graphics3D`'s `releaseTarget()` method to flush the rendered image to the 2D `Graphics`.
7. Call the 2D `Graphic`'s `flushGraphics()` method to flush the drawing and update the visible component with the rendered frame.

The typical usage of M3G for 3D graphics rendering is very similar to a 2D game loop. When used in conjunction with a `GameCanvas`, it will look like the following:

```
Graphics g = getGraphics();
Graphics3D g3d = Graphics3D.getInstance();

while(true) {

        g3d.bindTarget(g);

        // ...
        // Perform setup of the 3D scene to render.
        // ...

        g3d.render(...);

        mGraphics3D.releaseTarget();
        flushGraphics();

    }
```

If you compare the preceding rendering loop to the one used in the last chapter, in which we discussed the Game API, you will understand that it is essentially the same. The only exception is that now the M3G API is used to draw the graphics that will be displayed onto the 2D `Canvas`. In fact, this is the very essence of the M3G API: *it is used to draw graphics that represent a 3D scene onto a 2D display area.*

The M3G API encompasses many classes. Instead of covering all the details of every class in the confines of this chapter, only the foundations will be introduced. There will be three examples that allow you to see the API in action. These examples are designed for easy modification and experimentation with the full API.

To introduce some basic 3D graphics concepts and to cut through a bunch of frequently used M3G APIs, we'll start immediately with an example.

Getting Started with 3D

Many developers think that programming 3D graphics requires great mathematical skills. In reality, APIs such as M3G enable developers with little mathematical background to participate in the exciting world of 3D application programming.

Consider the `TriangleMIDlet`, shown in Figure 15-2. You can try it out from the source code download. This MIDlet simply rotates a triangle, which will appear red on your screen, in 2D when you start it. Watch it for a while.

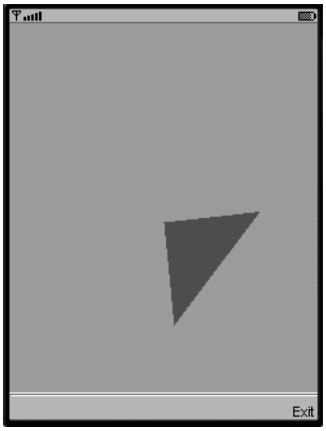


Figure 15-2. *TriangleMIDlet rotating a 2D triangle*

You should be able to imagine how you'd create this animation program without using a single line of M3G code:

1. Create a subclass of `Canvas`.
2. In the `paint()` method of the `Canvas` (or the animation loop for a `GameCanvas`), you will draw the triangle, and then set a timer to repaint. In each successive repaint (frame), you will draw the triangle in a new position. The coordinates can be calculated using simple trigonometry.
3. Create a MIDlet to host the custom `Canvas`.

Figure 15-3 shows how you can animate the triangle in this MIDlet.

In Figure 15-3, initially the three vertices `(0,0)`, `(3,0)`, and `(3,3)` define the triangle. Subsequent frames of the animation rotate the triangle around the origin at `(0,0)`.

Now that you are satisfied with your ability to create the same effect using MIDP's 2D graphics capability, we'll reveal to you that this animation is rendered using M3G. Yes, the M3G 3D API is used to rotate the triangle around the origin!

The geometry engine built into M3G understands the math of the rotation and recalculates the coordinates, plus redraws the triangle in each frame for you. All that you need to do is tell it the initial coordinates of the triangle and around what to rotate that triangle.

At this point, you are probably wondering what all of this has to do with 3D graphics. Here is the last secret that we have been keeping from you: the rotation you see in `TriangleMIDlet` is actually in 3D!

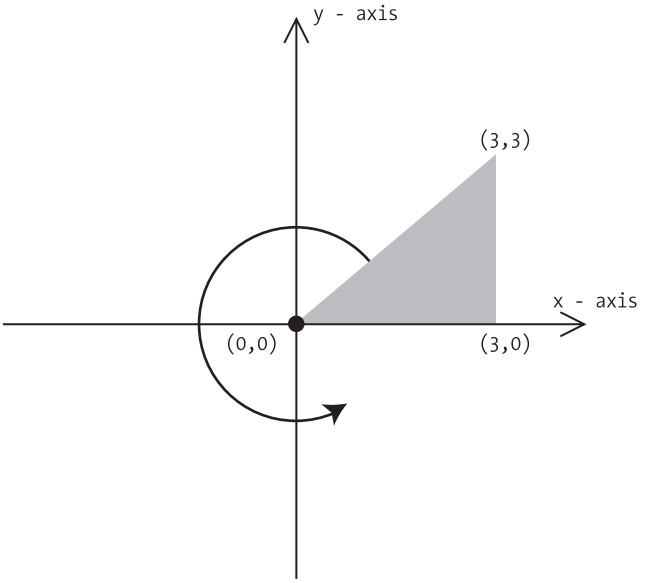


Figure 15-3. *Rotating a 2D triangle*

Rotating a Triangle in 3D

Take a quick look at Figure 15-4 to get an idea of what we mean.

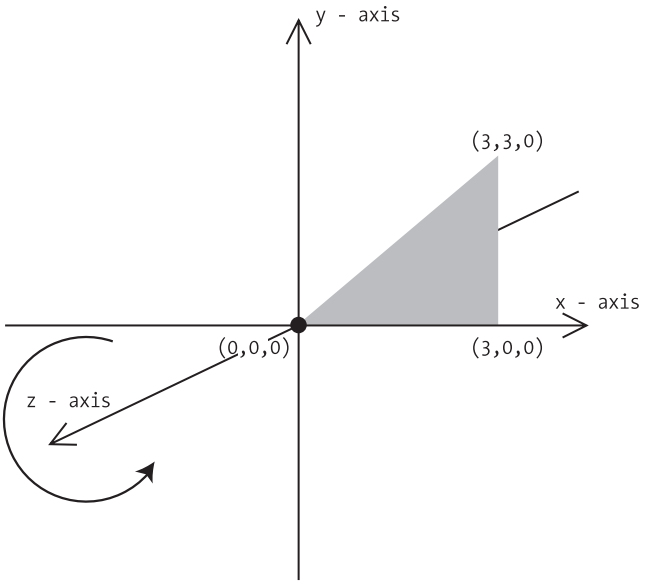


Figure 15-4. *TriangleMIDlet rotating a triangle in 3D*

M3G is actually rotating a 3-dimensional triangle around the z-axis. The z-axis in M3G points out towards you from the screen. In Figure 15-4, the vertices of the triangle actually point three dimensionally and have x, y, and z coordinates. However, all of their z coordinates have zero value. The 2D rotation that is observed is actually a 3D rotation in disguise.

If this is indeed the case, all that is required is to tell M3G to rotate the triangle around some axis other than the z-axis, and you should immediately see some 3D activity.

You can convince yourself of this by looking for the following line in the `TriangleCanvas` source code:

```
mTransform.postRotate(mAngle,  0, 0, 1.0f );
```

The last three numbers in this method invocation specify the vector around which the triangle will rotate—in this case `(0, 0, 1)`, or a vector parallel to the z-axis. Now, change the vector to `(1,0,0)`—a vector parallel to the x-axis:

```
mTransform.postRotate(mAngle,  1.0f, 0, 0 );
```

Build the MIDlet and run it again, and watch M3G rotate the triangle now in visible 3D, around the x-axis! Figure 15-5 shows the MIDlet in the midst of this 3D rotation.

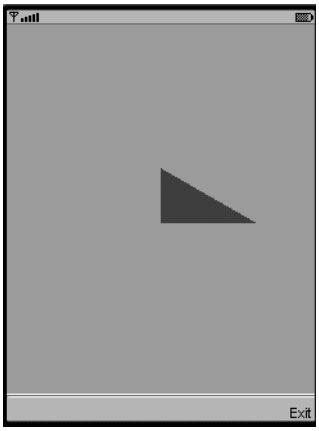


Figure 15-5. *TriangleMIDlet rotating the triangle around the x-axis*

The Effect of Culling

While the triangle shown in Figure 15-5 rotates around the x-axis, you will see the triangle disappear as it rotates away from you. After a while, it will start to rotate towards you again as it completes its clockwise rotation around the x-axis. The triangle seems to disappear for a moment because the back of the triangle is not rendered by M3G. This is due to an optimization technique known as *culling*. Culling avoids rendering surfaces that are never shown, and therefore saves on the computation required during rendering. Typically, the backside of triangles and polygons you define do not need to be rendered. Later, you will see how to disable culling, to make the triangle visible throughout its rotation.

Feeding M3G with Triangle Information

Examination of the code for `TriangleCanvas` will reveal how the triangle and rotation information is fed to M3G for rendering. The code for the `TriangleCanvas` is shown in Listing 15-1.

Listing 15-1. *The TriangleCanvas for Rotation of a Triangle in 3D*

```
import javax.microedition.lcdui.Graphics;
import javax.microedition.lcdui.game.*;
import javax.microedition.m3g.*;

public class TriangleCanvas extends GameCanvas implements Runnable {
    private boolean mRunning = false;
    private Thread mPaintThrd = null;
    private Graphics3D mGraphics3D = Graphics3D.getInstance();
    private Camera mCamera = new Camera();;
    private Light mLight = new Light();
    private float           mAngle = 0.0f;
    private Transform       mTransform = new Transform();
    private Background      mBackground = new Background();
    private VertexBuffer    mVertexBuffer;
    private IndexBuffer     mIndexBuffer;
    private Appearance      mAppearance = new Appearance();
    private Material        mMaterial = new Material();
    public TriangleCanvas() {
        super(true);
    }

    public void init()  {

        short[] vertices = { 0, 0, 0,  3, 0, 0,   0, 3, 0 };
        VertexArray vertexArray = new VertexArray(vertices.length / 3, 3, 2);
        vertexArray.set(0, vertices.length/3, vertices);

        byte[] normals = { 0, 0, 127,    0, 0, 127,    0, 0, 127 };
        VertexArray normalsArray = new VertexArray(normals.length / 3, 3, 1);
        normalsArray.set(0, normals.length/3, normals);

        VertexBuffer verbuf = mVertexBuffer = new VertexBuffer();
        verbuf.setPositions(vertexArray, 1.0f, null);
        verbuf.setNormals(normalsArray);

        int[] stripLength = { 3 };
        mIndexBuffer = new TriangleStripArray( 0, stripLength );
```

```
        mMaterial.setColor(Material.DIFFUSE, 0xFF0000);
        mMaterial.setColor(Material.SPECULAR, 0xFF0000);
        mMaterial.setShininess(100.0f);
        mAppearance.setMaterial(mMaterial);

        mBackground.setColor(0x00ee88);

        mCamera.setPerspective( 60.0f,
        (float)getWidth()/ (float)getHeight(),
        1.0f,
        1000.0f );

        mLight.setColor(0xffffff);
        mLight.setIntensity(1.25f);

    }

    public void start() {
        mRunning = true;
        mPaintThrd = new Thread(this);
        mPaintThrd.start();
    }

    public void stop() {
        mRunning = false;
        try{
            mPaintThrd.join();}
        catch (InterruptedException ex){}
    }

    public void run() {
        Graphics g = getGraphics();

        while(mRunning) {

            if (isShown()) {

                mGraphics3D.bindTarget(g);

                mGraphics3D.clear(mBackground);

                mTransform.setIdentity();
                mTransform.postTranslate(0.0f, 0.0f, 10.0f);
                mGraphics3D.setCamera(mCamera, mTransform);
```

```
                mGraphics3D.resetLights();
                mGraphics3D.addLight(mLight, mTransform);

                mAngle += 1.0f;
                mTransform.setIdentity();
                mTransform.postRotate(mAngle, 0, 0, 1.0f );
                mGraphics3D.render(mVertexBuffer, mIndexBuffer,
                                                    mAppearance, mTransform);

                mGraphics3D.releaseTarget();
                flushGraphics();
                try {Thread.sleep(40); }
                catch(InterruptedException ie){
                }

            }
        } // of while
      }  // of run()
    }
```

You can probably write your own `TriangleMIDlet` to contain the `TriangleCanvas`. The one used for this example is reproduced in Listing 15-2.

Listing 15-2. *TriangleMIDlet to Contain the TriangleCanvas*

```
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;
import java.util.*;

public class TriangleMIDlet extends MIDlet implements CommandListener {
    private Display mDisplay = null;
    private TriangleCanvas mCanvas = null;
    private Command exitCommand = new Command("Exit", Command.ITEM, 1);


    public TriangleMIDlet() {
        super();
        mDisplay = Display.getDisplay(this);
        mCanvas = new TriangleCanvas();
        mCanvas.setCommandListener(this);
        mCanvas.addCommand(exitCommand);
    }

    public void startApp()  {
        mCanvas.init();
        mDisplay.setCurrent(mCanvas);
        mCanvas.start();
    }
```

```
    public void pauseApp() {
    }

    public void destroyApp(boolean unconditional) {
     mCanvas.stop();
    }

    public void commandAction(Command cmd, Displayable disp) {
        if (cmd == exitCommand) {
            try {
                destroyApp(false);
                notifyDestroyed();
            }
            catch(Exception e) {
                e.printStackTrace();
            }
        }
    }
}
```

Lights, Camera, Action!

Creating a 3D scene is like shooting a film on a movie set. You need to create the objects to render, orchestrate their movement, set up light(s), and set up camera(s). The M3G API comes with a full set of classes to support this staging.

You can manually create the objects that will be rendered. In Listing 15-1, this involves the definition of the triangle and the rotation. The M3G engine needs to be informed of where the triangle is and what sort of appearance it should take on.

Defining Triangle Vertices

In Listing 15-1, the position of the initial triangle is specified in a `VertexArray` by the following code:

```
short[] vertices = { 0, 0, 0,  3, 0, 0,   0, 3, 0 };
VertexArray vertexArray = new VertexArray(vertices.length / 3, 3, 2);
vertexArray.set(0, vertices.length/3, vertices);
```

A `VertexArray` is an M3G class that holds an array of triplets—`(x,y,z)`. The elements of the array may represent vertex position, normals, texture, or color coordinates. Many methods in M3G take `VertexArray` as an input argument. In Listing 15-1, it holds the three vertices of the triangle.

There are two `set()` methods for `VertexArray`:

```
void set(int firstVertex, int numVertices, byte[] values);
void set(int firstVertex, int numVertices, short[] values);
```

The first version works with 8-bit `byte` values, while the second one works with 16-bit `short` values. In Listing 15-1, the 16 bit version is used to fill the `vertexArray` variable. The decision of which version to use will depend on what you will be using the resulting `VertexArray` for. In the next section, you will see that normals in M3G are defined in a `VertexArray` containing 8-bit values.

Defining Normals

During 3D rendering, a normal at a vertex tells the 3D engine which side of a triangle gets color and lighting effects. For example, consider Figure 15-6.

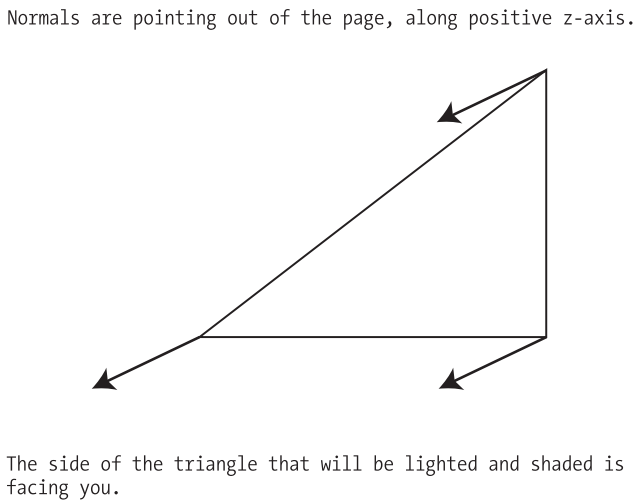

Normals are pointing out of the page, along positive z-axis.
The side of the triangle that will be lighted and shaded is facing you.

Figure 15-6. *Using normals to indicate which side of a triangle gets lighting and effects*

The code from Listing 15-1 that defines the normals is shown here:

```
byte[] normals = { 0, 0, 127,    0, 0, 127,    0, 0, 127 };
VertexArray normalsArray = new VertexArray(normals.length / 3, 3, 1);
normalsArray.set(0, normals.length/3, normals);
```

The normal of a surface is always perpendicular (at 90 degrees) to the surface itself. In Figure 15-6, each of the normals specified corresponds to a vertex of the triangle, specified in `vertexArray`. For example, corresponding to the vertex `(0,0,0)`, the normal is `(0,0, 127)`; and corresponding to the vertex `(0,3,0)`, the normal is `(0,0,127)`. The set of normals for the triangle tells M3G that the side of the triangle facing you is the side to light and render.

Combining Vertex Information into a VertexBuffer

The M3G class `VertexBuffer` is used to combine the position of vertices, their normals, and other associated information into one single data structure. This allows the input of most of the information for the skeletal frame of a 3D object into one single data structure. In Listing 15-1, a `VertexBuffer` called `verbuf` is created using this code:

```
VertexBuffer verbuf = mVertexBuffer = new VertexBuffer();
verbuf.setPositions(vertexArray, 1.0f, null);
verbuf.setNormals(normalsArray);
```

The two methods used in `VertexBuffer` are as follows:

```
void setPositions(VertexArray position, float scale, float [] bias);
void setNormals(VertexArray normals);
```

The `setPositions()` method has a `scale` and `bias` that can be used to modify the position values. Since the input values are integer values (in the `VertexArray`), using a float `scale` and a float `bias` allow you to convert these values into floating point numbers. This is one example of a computation optimization used in M3G to cater for the limitations (that is, little or no hardware support for floating-point calculations) of mobile devices. If you do specify a `scale` and `bias`, the `scale` will be used to multiply each of the three coordinates by; the bias is a three-element array, whereby the element values will be added to the x, y, and z components, respectively.

■ **Note** Specifying a float `scale` and `bias` can substantially slow down operations with a large `VertexBuffer` if the device in question does not have hardware floating-point support.

In Listing 15-1, no scaling or bias is used (by specifying a scale of 1 and null for bias).

Defining a Submesh with a TriangleStripArray

An object that can be rendered in M3G is contained in a submesh. In M3G 1.0, the only submesh available is a `TriangleStripArray`. The `TriangleStripArray` itself is a subclass of an `IndexBuffer`. An `IndexBuffer`, as its name implies, contain indices. An `IndexBuffer` is associated with a `VertexBuffer`; the indices contained in the `IndexBuffer` refer to the associated `VertexBuffer`. Specifically, the members of a `TriangleStripArray` tell M3G where the triangle strips are within the `VertexBuffer`. In Listing 15-1, the `TriangleStripArray` is defined with this code:

```
int[] stripLength = { 3 };
mIndexBuffer = new TriangleStripArray( 0, stripLength );
```

This tells M3G that only one single triangle is defined in the submesh, it starts at the index 0 in `verbuf`, and the number of indices occupied by this triangle is 3. In other words, M3G will use the first three indices in the `verbuf` `VertexBuffer` to render the object.

Giving Your Submesh an Appearance

In Listing 15-1, the code that associates an appearance with the triangle submesh is as follows:

```
Material mMaterial = new Material();
Appearance mAppearance = new Appearance();
Background mBackground = new Background();
....
```

```
mMaterial.setColor(Material.DIFFUSE, 0xFF0000);
mMaterial.setColor(Material.SPECULAR, 0xFF0000);
mMaterial.setShininess(100.0f);
mAppearance.setMaterial(mMaterial);

mBackground.setColor(0x00ee88);
```

An `Appearance` is an M3G class that groups together a set of objects that control how a submesh will appear when it is rendered. These objects are called *rendering attributes*. One of the rendering attributes is `Material`. As the name implies, the `Material` attribute controls the color and how light will reflect off the submesh being rendered. In the preceding code, the `Material` is set to be `DIFFUSE` and `SPECULAR`, with a red color (an RGB value of `0xFF0000`). The possible values for the first parameter of the `setColor()` method of a `Material` are listed in Table 15-1.

Table 15-1. *Possible Values for Specifying the Reflective Quality of a Material's Color*

Value	Description
`AMBIENT`	The ambient color component, the color of the material that is revealed by ambient (evenly distributed) lighting
`DIFFUSE`	The diffuse color component, the color of the material that is revealed by a directional lighting
`EMISSIVE`	The emission color component, the color of the material that appears to be glowing
`SPECULAR`	The specular color component, the color displayed in the reflection highlights

The `setShininess()` method controls how shiny the material appears to be. It actually adjusts the concentration of the specular lighting component and can take on a value from 0 (dull) to 128 (very shiny).

The `Background` object is an M3G object that is used to render the background. You can specify either a color or an `Image2D`. These are the methods of `Background` to set color or image:

```
void setColor(int rgbColor);
void setImage(Image2D  image);
```

In the code in Listing 15-1, the `Background` of our rendering is set to a light green color (RGB value of `0x00ee88`).

In summary, the code in the `init()` method of Listing 15-1 places a shiny red triangle against a light green background for the 3D rendering.

Setting Up Light and Camera

The last part of the `init()` method sets up the light and camera. `Camera` is an M3G class that controls what you see in the rendering. It has a position and an orientation. In addition, you can control other attributes such as the field of view, the aspect ratio, and clipping panes. These

attributes tell M3G how much of the scene needs to be computed and rendered; anything outside of the field of view and clipping panes is not computed.

The following code from Listing 15-1 sets up the `Camera` to have a 60-degree field of view (controls how much of the scene you can see), an aspect ratio that is the same as the `Canvas`, and two clipping panes that allow you to see the entire triangle when it is rotated.

```
mCamera.setPerspective( 60.0f,  (float)getWidth()/ (float)getHeight(),
   1.0f, 1000.0f );

mLight.setColor(0xffffff);
mLight.setIntensity(1.25f);
```

Like a `Camera`, a `Light` is an M3G object that has a position and an orientation. It can also have other attributes such as a color, different modes (for example, spotlight versus diffused light), intensity, etc. Here, the color of our light is set to white (RGB `0xffffff`), and its intensity is set to slightly brighter than default (default is a directional spotlight with an intensity of 1).

Transforms: Moving 3D Objects About

Each frame of a 3D animation is rendered through an iteration of the `while` loop within the `run()` method. A fragment of the code from this loop is reproduced here:

```
mGraphics3D.bindTarget(g);
mGraphics3D.clear(mBackground);

mTransform.setIdentity();
mTransform.postTranslate(0.0f, 0.0f, 10.0f);
mGraphics3D.setCamera(mCamera, mTransform);

mGraphics3D.resetLights();
mGraphics3D.addLight(mLight, mTransform);
```

Here is what is happening in the code:

- First, the `Graphics3D` instance is bound to the `Canvas`'s `Graphics` context.
- Next, the `Background` is cleared out.
- Then the `Camera` and `Light` are moved around the scene.

`Transform` is an M3G object that can be used to move objects around the 3D world. To those familiar with 3D math, this type of object actually encapsulates a 4×4 matrix that will be multiplied with the coordinates of a 3D mesh to achieve scaling, translation, rotation, and orientation. However, it is not necessary to know the mathematical details to work with a `Transform`. A `Transform` has the following methods:

```
void setScale(float sx, float xy, float sz);
void setTranslation(float tx, float ty, float tz);
void preRotate(float angle, float ax, float ay, float az);
void postRotate(float angle, float ax, float ay, float az);
void setOrientation(float angle, float ax, float ay, float az);
```

The rotation and orientation methods take an angle and an axis of revolution as parameters. `preRotate()` is applied before the translation, and `postRotate()` is applied after the translation. Using these methods, you can manipulate the coefficients in the `Transform` matrix without knowing the math involved.

In the Listing 15-1 code, shown earlier in this section, the camera is moved to `(0,0, 10)`. This is 10 units towards the viewer along the z-axis. When the camera is first created, it is located at `(0,0,0)` and pointing towards the z-axis (into the display).

The single light is also placed in the same position as the camera, giving the camera a "headlight" pointing at the direction of the view.

The final code in the rendering loop actually rotates the triangle submesh. The same `Transform` is reused here to save some memory. Calling `setIdentity()` on the `Transform` basically resets it to a `Transform` that performs no translation, scaling, or rotation. Then the `postRotate()` method is used to rotate the triangle one degree per frame around the axis of choice (z-axis in this case).

```
  mAngle += 1.0f;
  mTransform.setIdentity();
  mTransform.postRotate(mAngle,       // Rotate 1 degree per frame
  0, 0, 1.0f );
mGraphics3D.render(mVertexBuffer, mIndexBuffer,
                                          mAppearance, mTransform);
```

The call to `render()` will actually draw a 3D frame into the bound 2D `Graphics` instance. The `Light` and `Camera` have already been set up earlier using the `Graphics3D` instance. Notice how `Graphic3D`'s `render()` method takes the `VertexBuffer`, the `IndexBuffer` (`TriangleStripArray`), the `Appearance`, and the `Transform` to perform its work.

Experimentation with Culling

`TriangleCanvas` is a great framework for experimenting with the M3G APIs. You can try moving the light, camera, and triangle around; or try working with different `Material` and `Appearance` attributes, etc. All you need is a copy of the Javadoc of the JSR 184 for reference.

As an example, we'll disable culling. Disabling culling will let you see the "back" of the triangle rendered. To add code to disable culling, look inside the `init()` method and insert the following highlighted code:

```
mAppearance.setMaterial(mMaterial);
PolygonMode tPoly = new PolygonMode();
tPoly.setCulling(PolygonMode.CULL_NONE);
mAppearance.setPolygonMode(tPoly);
mBackground.setColor(0x00ee88);
```

`PolygonMode` is an M3G class representing a rendering attribute. It is grouped by an `Appearance` instance and can be used to control culling. In this code, it is set to `CULL_NONE`, allowing the back of the triangle to be rendered. The default is `CULL_BACK`.

Assuming that you have modified `TriangleCanvas` to rotate the triangle around the x-axis, rebuild the MIDlet and run it. You should now see both sides of the triangle rendered during the rotation. Notice, however, that only the side with the vertex normals is rendered with light and color.

Understanding Triangle Strips

It is very important to understand what a triangle strip is and why it is used in M3G. As the name implies, a triangle strip is a strip of triangles. In `TriangleCanvas`, this strip contains just one single triangle. M3G allows for a strip with an arbitrary number of triangles.

Recall from basic geometry that any polygon can be decomposed into a number of triangles. This means that a triangle strip can be used to create any arbitrary polygon.

Because all triangles in a strip share common side(s) with others, `TriangleStripArray` in M3G can use a compact way of specifying vertices for multiple triangles. To specify one triangle, you will need three vertices; to specify two adjoining triangles, you will need only four vertices; to specify three, you need five vertices, and so on.

Take as an example a square composed of two triangles, as shown in Figure 15-7.

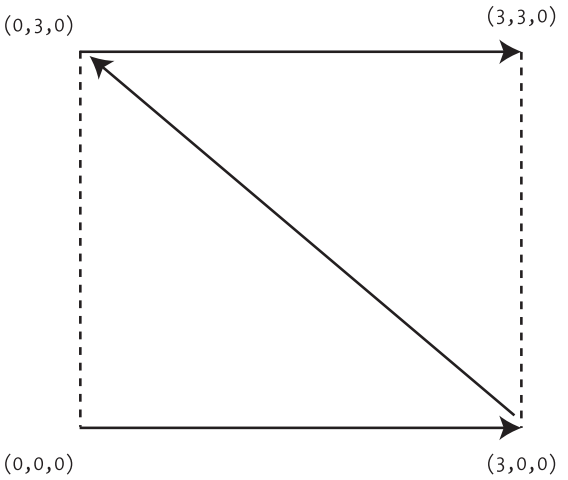


Figure 15-7. *Using four vertices to describe two triangles forming a square*

In Figure 15-7, you can see how four vertices—`(0,0,0)`, `(3,0,0)`, `(0,3,0)`, and `(3,3,0)`—are sufficient to describe this strip of two triangles.

Modifying TriangleCanvas to Rotate a Square

We'll continue our experimentation with M3G APIs using `TriangleCanvas` by modifying it to display a rotating square instead of a triangle.

You will need to specify one more vertex for the triangle strip:

```
short[] vertices = { 0, 0, 0,  3, 0, 0,   0, 3, 0 ,  3,3,0  };
 VertexArray vertexArray = new VertexArray(vertices.length / 3, 3, 2);
 vertexArray.set(0, vertices.length/3, vertices);
```

One more vertex means an additional normal:

```
byte[] normals = { 0, 0, 127,    0, 0, 127,    0, 0, 127, 0,0, 127 };
VertexArray normalsArray = new VertexArray(normals.length / 3, 3, 1);
normalsArray.set(0, normals.length/3, normals);
```

The length of the TriangleStripArray instance also needs to be changed:

```
int[] stripLength = { 4};
mIndexBuffer = new TriangleStripArray( 0, stripLength );
```

Make the preceding modifications to the TriangleCanvas code, and rebuild and run it. You will see a red square rotating instead of a triangle. Using the same technique, you can create and rotate any abitrary polygon.

Rotating a 3D Corner Piece

The second example is actually an evolution of the TriangleMIDlet. It rotates a section of a cube in 3D. Try this out by running the CornerMIDlet example. When you copy over the source files, make sure you have included the texture.png file and placed it into the res directory of the WTK application. Figure 15-8 shows the CornerMIDlet running.

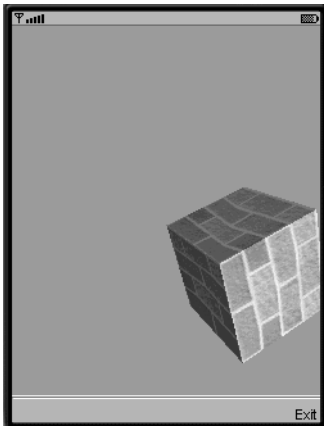


Figure 15-8. *CornerMIDlet rotating the corner of a cube*

In Figure 15-8, you see the corner of a cube that has a brick exterior being rotated in 3D. The code to perform this rotation is in the CornerCanvas class, which has the exact same general structure as TriangleMIDlet. The source code of CornerCanvas is shown in Listing 15-3.

Listing 15-3. *CornerCanvas—Rotating a Texture-Mapped Cube*

```
import javax.microedition.lcdui.*;
import javax.microedition.m3g.*;
import javax.microedition.lcdui.game.*;

public class CornerCanvas extends GameCanvas implements Runnable {
    private boolean mRunning = false;
    private Thread mPaintThrd = null;
```

```
private Graphics3D mGraphics3D = Graphics3D.getInstance();
private Camera mCamera = new Camera();;
private Light mLight = new Light();
private float           mAngle = 0.0f;
private Transform       mTransform = new Transform();
private Background      mBackground = new Background();
private VertexBuffer    mVertexBuffer;
private IndexBuffer     mIndexBuffer;
private Appearance      mAppearance = new Appearance();
private Material        mMaterial = new Material();
private Image           mImage;
public CornerCanvas() {
    super(true);
}

public void init()  {

    short[] vertices = {
        0, 0, 0,  3, 0, 0,  0, 3,  0,  3, 3,  0,
        3, 0, 0,  3, 3, 0,  3, 0, -3,  3, 3, -3,
        0, 0, 0,  3, 0, 0,  0, 0, -3,  3, 0, -3
    };

    VertexArray vertexArray = new VertexArray(vertices.length / 3, 3, 2);
    vertexArray.set(0, vertices.length/3, vertices);

    byte[] normals = {
        0,      0, 127,    0,    0, 127,     0,  0,  127,    0,    0, 127,
        127,    0,   0,  127,    0,   0,   127,  0,    0,  127,    0,   0,
        0,   -127,   0,    0, -127,   0,     0, -127,  0,    0, -127,   0
    };

    VertexArray normalsArray = new VertexArray(normals.length / 3, 3, 1);
    normalsArray.set(0, normals.length/3, normals);

    short[] texturecords = {
        0,1,     1,1,    0,  0,  1,  0,
        0,1,     0,0,    1,  1,  1,  0,
        0,0,     1,0,    0,  1,  1,  1  };

        VertexArray textureArray =
        new VertexArray(texturecords.length / 2, 2, 2);
        textureArray.set(0, texturecords.length/2, texturecords);
```

```
        VertexBuffer verbuf = mVertexBuffer = new VertexBuffer();
        verbuf.setPositions(vertexArray, 1.0f, null);
        verbuf.setNormals(normalsArray);
        verbuf.setTexCoords(0, textureArray, 1.0f, null);
        int[] stripLength = { 4, 4, 4};
        mIndexBuffer = new TriangleStripArray( 0, stripLength );
        try {
            mImage = Image.createImage( "/texture.png" );
        } catch (Exception ex) {
            ex.printStackTrace();
        }

        Image2D image2D = new Image2D( Image2D.RGB, mImage );
        Texture2D texture = new Texture2D( image2D );

        mAppearance.setTexture(0, texture);
        mAppearance.setMaterial(mMaterial);
        mMaterial.setColor(Material.DIFFUSE, 0xffffffff);
        mMaterial.setColor(Material.SPECULAR, 0xffffffff);
        mMaterial.setShininess(100.0f);

        PolygonMode tPoly = new PolygonMode();
        tPoly.setCulling(PolygonMode.CULL_NONE);
        mAppearance.setPolygonMode(tPoly);
        mBackground.setColor(0xffeecc);

        mCamera.setPerspective( 60.0f,
        (float)getWidth()/ (float)getHeight(),
        1.0f,
        100.0f );

        mLight.setColor(0xffffff);
        mLight.setIntensity(1.25f);


}


public void start() {
    mRunning = true;
    mPaintThrd = new Thread(this);
    mPaintThrd.start();
}
```

```
    public void stop() {
        mRunning = false;
        try{
            mPaintThrd.join();}
        catch (InterruptedException ex){}
    }

    public void run() {
        Graphics g = getGraphics();

        while(mRunning) {

            if (isShown()) {

                mGraphics3D.bindTarget(g, true,
                Graphics3D.DITHER |
                Graphics3D.TRUE_COLOR);

                mGraphics3D.clear(mBackground);

                mTransform.setIdentity();
                mTransform.postTranslate(0.0f, 0.0f, 10.0f);
                mGraphics3D.setCamera(mCamera, mTransform);

                mGraphics3D.resetLights();
                mGraphics3D.addLight(mLight, mTransform);

                mAngle += 1.0f;
                mTransform.setIdentity();
                mTransform.postRotate(mAngle,
                1.0f, 1.0f, 1.0f );
                mGraphics3D.render(mVertexBuffer, mIndexBuffer,
                mAppearance, mTransform);

                mGraphics3D.releaseTarget();

                flushGraphics();
                try {Thread.sleep(40); }
                catch(InterruptedException ie){
                }

            }
        }
    }

}
```

Defining Triangle Strips for the Corner Submesh

The corner of the cube is defined as three separate triangle strips. The vertices for these strips are specified in the same vertex buffer and loaded into the M3G rendering engine via an index buffer—the `TriangleStripArray`. The `TriangleStripArray` keeps track of where one strip ends and another starts.

The vertices for each of the strips are as follows:

- Strip 1 (square in the x-y plane): `(0,0,0)`, `(3,0,0)`, `(0,3,0)`, `(3,3,0)`
- Strip 2 (square in the y-z plane): `(3,0,0)`, `(3,3,0)`, `(3,0,-3)`, `(3,3,-3)`
- Strip 3 (square in the x-z plane): `(0,0,0)`, `(3,0,0)`, `(0,0,-3)`, `(3,0,-3)`

The code to create the `vertexArray` in Listing 15-3 is shown here:

```
short[] vertices = {
     0, 0, 0,  3, 0, 0,  0, 3,  0,  3, 3,  0,
     3, 0, 0,  3, 3, 0,  3, 0, -3,  3, 3, -3,
     0, 0, 0,  3, 0, 0,  0, 0, -3,  3, 0, -3
 };

 VertexArray vertexArray = new VertexArray(vertices.length / 3, 3, 2);
 vertexArray.set(0, vertices.length/3, vertices);
```

Corresponding to the vertices, the normals are defined as follows:

```
byte[] normals = {
    0,      0, 127,    0,    0, 127,     0,  0,  127,    0,    0, 127,
    127,    0,   0,  127,    0,   0,   127,  0,    0,  127,    0,   0,
    0,   -127,   0,    0, -127,   0,     0, -127,  0,    0, -127,   0
};

VertexArray normalsArray = new VertexArray(normals.length / 3, 3, 1);
normalsArray.set(0, normals.length/3, normals);
```

Texture Mapping the Cube Exterior

To make the exterior of the cube take on a brick-like appearance, texture mapping will be used. *Texture mapping* is the action of painting a texture (an image) over a 3D surface, like using wrapping paper to wrap a gift.

Obviously, you will first need an image that represents a texture. M3G has the `Image3D` class, which can be used in a texture. Here is one of the constructors for `Image3D`:

```
public Image2D(int format, Object image);
```

The format parameter to the constructor can be one of the following:

```
Image2D.RGB
Image2D.RGBA
Image2D.ALPHA
Image2D.LUMINANCE
Image2D.LUMINANCE_ALPHA
```

The first constant is used for the RGB pixel format, such as the data from an MIDP `Image` object. The alpha channel is typically used to indicate transparency on systems that support it. Luminance is an alternative way of encoding pixel data, typically used for monochrome images.

The second parameter can be an `Image` object from MIDP, allowing texture images to be easily loaded from resource with code similar to the following:

```
mImage = Image.createImage( "/texture.png" );
Image2D image2D = new Image2D( Image2D.RGB, mImage );
```

Applying Texture Image to Triangle Strips

Once you have an image, you need to tell M3G how to map it to the triangle strips. This is done through another vertex attribute called a *texture coordinate*. Figure 15-9 shows how the texture is mapped to a surface (square) using texture coordinates.

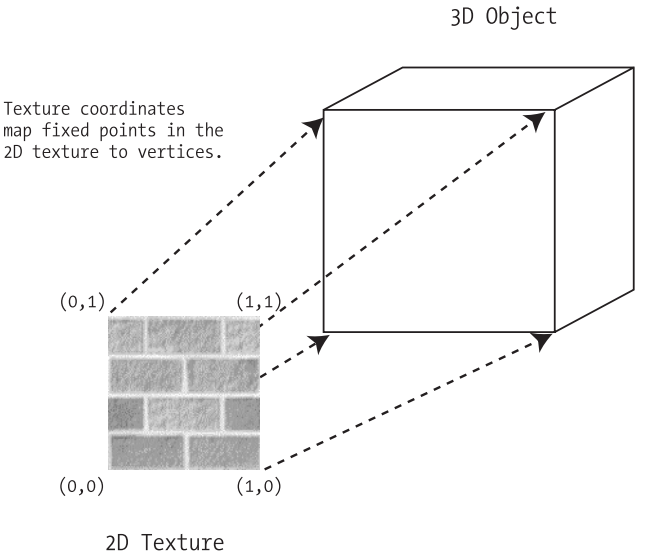


Figure 15-9. *Texture mapping a 3D surface*

In Figure 15-9, you can see that the texture coordinates essentially tell M3G how to place the texture on the surface by anchoring specific texture points to the vertices.

The code that performs the assignment of the texture coordinates to a `VertexArray` from Listing 15-3 is reproduced here:

```
short[] texturecords = {
    0,1,     1,1,    0,  0,  1,  0,
    0,1,     0,0,    1,  1,  1,  0,
    0,0,     1,0,    0,  1,  1,  1  };

    VertexArray textureArray =
    new VertexArray(texturecords.length / 2, 2, 2);
    textureArray.set(0, texturecords.length/2, texturecords);
```

Since the texture is only in 2D, there is only an (x,y) coordinate associated with each vertex.

In TriangleCanvas, the vertices and normals are combined into a VertexBuffer for rendering. Here in CornerCanvas, the texture coordinate is added into the same VertexBuffer:

```
VertexBuffer verbuf = mVertexBuffer = new VertexBuffer();
verbuf.setPositions(vertexArray, 1.0f, null);
verbuf.setNormals(normalsArray);
verbuf.setTexCoords(0, textureArray, 1.0f, null);
```

A TriangleStripArray is then built to tell M3G where each of the four strips are within the VertexBuffer:

```
int[] stripLength = { 4, 4, 4};
mIndexBuffer = new TriangleStripArray( 0, stripLength );
```

Here, the first triangle strip starts at index 0 and has a length of 4. Subsequently, there are two more triangle strips of length 4.

The last piece of code that is required creates the texture from the Image2D and adds it to Appearance. Texture2D is a rendering attribute that is grouped by an Appearance object, just like Material and PolygonMode. The code from Listing 15-3 that is responsible for adding Texture2D to Appearance is shown here:

```
Texture2D texture = new Texture2D( image2D );
mAppearance.setTexture(0, texture);
```

That is all there is to the texture-mapping code. You should be able to see how you can build complex 3D scenes out of submeshes, applying texture and material to them, lighting them up, and then transforming them.

In reality, to create even a moderately complex 3D object—say, a jumping kangaroo—you may have to define hundreds of triangles. Even a simple 3D scene usually requires a few 3D objects, which means many vertices and a lot of M3G code! There must be a simpler solution.

Immediate Mode vs. Retained Mode

The simpler solution is to use the retained mode of the M3G API.

Thus far, all the examples have used the M3G API in immediate mode. Immediate mode provides low-level access to the rendering process, very close to the rendering engine. This level of access is similar to access provided by other industry-standard embedded 3D APIs such as OpenGL ES. Immediate mode works with the 3D scenes in terms of vertices, normals, transforms, appearance, etc.

Retained mode provides a significantly higher level of access to a 3D world (often called a *scene graph*).

High-Level Access to a Scene Graph via Retained Mode

A 3D world in retained mode can contain all the 3D objects in a scene prebuilt (all vertices, texture, normals, etc., specified) and in position; lights and cameras are predefined and in position, transformation can also be predefined, and animation can also be created beforehand.

The M3G application then simply activates or stages the animation and the transformation using high-level scene-graph control APIs.

The Elusive .m3g Serialized Scene Graph File Format

The 3D world used in retained mode is typically not painstakingly built using M3G APIs, but loaded from a file. In fact, JSR 184 specifies a file format, with the extension `.m3g`, that is used to store these serialized 3D worlds.

Using the retained mode in M3G literally involves the following steps:

1. Loading a complete serialized 3D world from a `.m3g` file
2. Rendering an animation using the newly loaded 3D world

What is not obvious, however, is how you would create the prefabricated 3D world (the `.m3g` file) in the first place. In fact, the M3G API cannot be used to create a `.m3g` file. There is no API call to serialize a 3D world.

Creating a .m3g File

The idea is to use a sophisticated 3D modeling package on a high-powered workstation (and not on your mobile device) to create your 3D world.

Once the world (all the objects, transformations, animations, etc.) are created, a `.m3g` file can then be generated. This `.m3g` file can then be moved to a mobile device and used within an application.

At the time of writing, however, very few sources exist for sophisticated 3D modeling packages that will generate `.m3g` worlds.

Superscape (`http://www.superscape.com/`) has a product called Swerve that can create these `.m3g` files. Unfortunately, Superscape has not yet made this tool available to the general public.

Autodesk's 3D Studio Max, Version 7 (`http://usa.autodesk.com/`) has the capability to export `.m3g` files. However, the exporter deals mainly with the creation of 3D objects, but does not have the ability to define and serialize animation.

HI Corporation (`http://www.hicorp.co.jp/e_index.html`) is also reported to have a `.m3g` exporter utility to export 3D models from Autodesk's 3D Studio Max and NewTek's LightWave.

So you see, it is not quite possible yet, unless you are up to creating your own 3D modeling tool, for you to easily make use of M3G's retained mode of operation.

Working with Retained Mode

Our last example will provide you with some hands-on experience with animating a retained mode 3D world.

Without the ability to create complete `.m3g` files, in this the example we'll use a prefabricated `.m3g` file from the Wireless Toolkit's 3D samples. This 3D world is created using Superscape's Swerve tool.

To try out this example, create a new project called `RMMIDlet` and copy the source code files into the `src` directory of the newly created application.

The .m3g file that you will need is called pogoroo.m3g. You can find it at the following path:

```
<WTK 2.2 inst. dir.>/apps/Demo3D/res/com/superscape/m3g/wtksamples/pogoroo/content
```

Copy this .m3g file to the res directory of the RMMIDlet project.

Now build and run the MIDlet. You will see a 3D kangaroo jumping up and down in front of you. Use the navigation keys on the phone emulator to move the camera around the kangaroo's world. Figure 15-10 shows the RMMIDlet in action.

Figure 15-10. *Interacting with a retained mode 3D world*

The custom GameCanvas subclass in this MIDlet is called RetainedCanvas. The source code for RetainedCanvas is shown in Listing 15-4.

Listing 15-4. *RetainedCanvas for Interacting with a Retained Mode 3D World*

```
import javax.microedition.lcdui.Graphics;
import javax.microedition.lcdui.game.*;
import javax.microedition.m3g.*;

class RetainedCanvas  extends GameCanvas implements Runnable {
    private boolean mRunning = false;
    private Thread mPaintThrd = null;

    private Graphics3D mGraphics3D = Graphics3D.getInstance();
    private World mWorld = null;
    private Camera mCam = null;
    private long mWorldStartTime = 0;

    public RetainedCanvas() {
        super(true);
    }
```

```
public  void init() {
    try {
        mWorld = (World) Loader.load("/pogoroo.m3g")[0];
        mCam = mWorld.getActiveCamera();
        mCam.translate(0, 0, -1.5f);
        mCam.setOrientation(180, 0, 1,  0);
    }
    catch(Exception e) {
        e.printStackTrace();
    }
    mWorldStartTime = System.currentTimeMillis();

}

public void start() {
    mRunning = true;
    mPaintThrd = new Thread(this);
    mPaintThrd.start();
}

public void stop() {
    mRunning = false;
    try{
        mPaintThrd.join();}
    catch (InterruptedException ex){}
}

public void run() {
    Graphics g = getGraphics();
    long startTime;

    while(mRunning) {

        if (isShown()) {
            int keyStates = getKeyStates();
            if ((keyStates & UP_PRESSED) != 0) {
                cameraForward();
            }
            else if ((keyStates & DOWN_PRESSED) != 0) {
                cameraBackward();
            }
            else if ((keyStates & LEFT_PRESSED) != 0) {
                cameraLeft();
            }
            else if ((keyStates & RIGHT_PRESSED) != 0) {
                cameraRight();
            }
```

```
                startTime = System.currentTimeMillis() - mWorldStartTime;
                mWorld.animate((int)startTime);
                mGraphics3D.bindTarget(g);
                mGraphics3D.render(mWorld);
                mGraphics3D.releaseTarget();
                flushGraphics();
                try {Thread.sleep(100); }
                catch(InterruptedException ie){
                }

            }
        } // of while
    }


    private void cameraForward() {
        mCam.translate(0f, 0f, 0.2f);
    }
    private void cameraBackward() {
        mCam.translate(0f, 0f, -0.2f);

    }
    private void cameraLeft() {
        mCam.translate(-0.2f, 0f, 0f);

    }
    private void cameraRight() {
        mCam.translate(0.2f, 0f, 0f);
    }

}
```

You can write the MIDlet container class yourself, or download it from `http://www.apress.com/`.

Loading a Retained Mode 3D World

`RetainedCanvas` is a subclass of `GameCanvas`. This MIDlet takes advantage of `GameCanvas`'s easy key polling and the simple rendering loop.

To load the retained mode world, an M3G `Loader` class is used. The sole purpose of a `Loader` is to load in and reconstitute an instance of an `Object3D` subclass. `Object3D` subclasses include many of the objects you've encountered, such as `VertexBuffer`, `VertexArray`, `Material`, `PolygonMode`, and so on. `World` is also an `Object3D` subclass.

A `World` is a complete serialized 3D world, including all the 3D objects, transformation, light, camera, animation, etc.

Also, a `World` is a specialized `Group`, another M3G class. A `Group` can contain multiple other `Nodes`. A `Node` can be a `Camera`, `Mesh`, `Light`, `Group`, or `Sprite3D`. This forms the data structure that

allows a World to contain everything in a scene. The code from Listing 15-4 to load the .m3g file is as follows:

```
World mWorld;
...
mWorld = (World) Loader.load("/pogoroo.m3g")[0];
```

Once a World is created, you can use some of its methods to obtain familiar objects. The active Camera is obtained using this method:

```
Camera getActiveCamera();
```

The Background is obtained using this method:

```
Background getBackgroud();
```

In addition, the 3D modeling tool used to create the .m3g file will allow you to assign special integer IDs to any Object3D subclass that you create. You can then use the find() method to locate any object within the World:

```
Object3D find(int userID);
```

Retrieving the Active Camera in the Retained Mode World

In Listing 15-4, the Camera is retrieved from the World and moved to the front of the jumping kangaroo. The following code from the init() method illustrates this:

```
mCam = mWorld.getActiveCamera();
mCam.translate(0, 0, -1.5f);
mCam.setOrientation(180, 0, 1,  0);
```

It is necessary to change the orientation of the Camera. Initially, the Camera is facing the back of the kangaroo in the World defined within the .m3g file.

Rendering a Retained Mode World

Rendering a frame in retained mode is significantly simpler than in immediate mode. The code in the rendering loop that follow is from Listing 15-4:

```
startTime = System.currentTimeMillis() - mWorldStartTime;
mWorld.animate((int)startTime);
mGraphics3D.bindTarget(g);
mGraphics3D.render(mWorld);
mGraphics3D.releaseTarget();
flushGraphics();
```

The animate() method on the World is called to animate the hopping kangaroo (using predefined animation within the World). The entire World is rendered using the Graphic3D's retained mode rendering method:

```
void render(World world);
```

Also within the loop of the `run()` method is code to poll the keyboard and then move the `Camera` accordingly.

Summary

This chapter describes the Mobile 3D Graphics, or M3G, optional API specified by JSR 184. M3G, which brings powerful 3D rendering capability to mobile devices, has a high-level retained mode and a lower-level immediate mode of operation. Using the M3G API, you can render 3D graphics to a 2D MIDP component such as a `Canvas` by binding to the singleton `Graphics3D` instance.

In immediate mode, `Graphics3D` controls `Lights` for illuminating 3D scene and `Camera` to determine the portion of the scene that is displayed. You can create 3D meshes by specifying an array of triangle strips using the `TriangleStripArray` class. Each triangle strip contains vertices that describe a set of adjoining triangles. `VertexArray` is used to contain the vertices information, while a `VertexBuffer` holds associated normals as well as texture coordinates. An `Appearance` object can be associated with a triangle strip; it controls the material, culling, and texture map used during 3D rendering. A 3D object can be moved within the 3D scene by defining a `Transform`. A `Transform` provides scaling, translation, and rotation for a 3D object.

Retained mode allows a prefabricated 3D world to be loaded from a standard `.m3g` file. The entire world can be animated and rendered using the high-level retained mode API. In addition, the objects inside the world can be located and manipulated using immediate mode API calls.

CHAPTER 16

Sound, Music, and Video: MMAPI

MIDP includes basic audio capabilities. The media APIs are a strict subset of the Mobile Media API (MMAPI), a more general API for multimedia rendering. The full details on MMAPI are in JSR 135:

```
http://jcp.org/jsr/detail/135.jsp
```

The MMAPI itself is kind of a pint-sized version of the Java Media Framework (JMF), which is an optional package for J2SE. More information on the JMF is available here:

```
http://java.sun.com/products/java-media/jmf/
```

The subset of the MMAPI that is included is called the Audio Building Block (ABB). It includes the capability to play simple tones and sampled audio. The ABB is implemented in the `javax.microedition.media` and `javax.microedition.media.control` packages. This chapter covers all of MIDP's ABB support and the most commonly found features of MMAPI—including video handling. It begins with a rush of runnable code, and then backs off to explain some of the concepts and dig into the APIs more carefully.

Quick Start

You can play tones by calling this method in `javax.microedition.media.Manager`:

```
public static void playTone(int note, int duration, int volume)
```

In this method, `note` is specified just like a MIDI note, where each integer corresponds to a single key on a piano keyboard. Middle C is 60, and the A above middle C (a 440 Hz tone) is 69. The `duration` is in milliseconds, and `volume` can range from `0`, silent, to `100`, loudest.

Like most other methods in the ABB, `playTone()` may throw a `MediaException`. Although support for simple tones is required by the specification, the device may be temporarily unable to play tones. (For example, a mobile phone might be using the tone generation hardware to ring the phone.)

Figure 16-1 shows `PianoCanvas`, an example that displays a simple piano keyboard and allows the user to navigate through the keys to play different tones. `PianoCanvas` is presented in Listing 16-1. The code for playing the tones is very compact, consisting solely of a call to `playTone()` in the `keyPressed()` method. The rest of the code is devoted to the user interface.

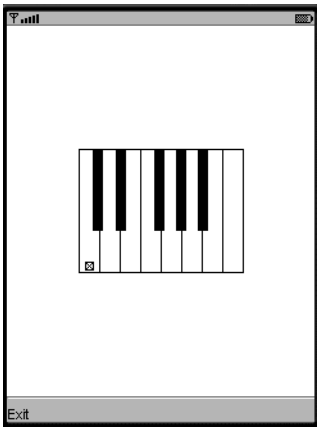


Figure 16-1. *An itty bitty piano*

Listing 16-1. *PianoCanvas Source Code*

```
import javax.microedition.lcdui.*;
import javax.microedition.media.*;

public class PianoCanvas
    extends Canvas {
  private static final int[] kNoteX = {
     0, 11, 16, 29, 32, 48, 59, 64, 76, 80, 93, 96
  };

  private static final int[] kNoteWidth = {
    16,  8, 16,  8, 16, 16,  8, 16,  8, 16,  8, 16
  };

  private static final int[] kNoteHeight = {
    96, 64, 96, 64, 96, 96, 64, 96, 64, 96, 64, 96
  };

  private static final boolean[] kBlack = {
    false, true, false, true, false,
        false, true, false, true, false, true, false
  };

  private int mMiddleCX, mMiddleCY;

  private int mCurrentNote;
```

```
public PianoCanvas() {
  int w = getWidth();
  int h = getHeight();

  int fullWidth = kNoteWidth[0] * 8;
  mMiddleCX = (w - fullWidth) / 2;
  mMiddleCY = (h - kNoteHeight[0]) / 2;

  mCurrentNote = 60;
}

public void paint(Graphics g) {
  int w = getWidth();
  int h = getHeight();

  g.setColor(0xffffff);
  g.fillRect(0, 0, w, h);
  g.setColor(0x000000);

  for (int i = 60; i <= 72; i++)
    drawNote(g, i);

  drawSelection(g, mCurrentNote);
}

private void drawNote(Graphics g, int note) {
  int n = note % 12;
  int octaveOffset = ((note - n) / 12 - 5) * 7 * kNoteWidth[0];
  int x = mMiddleCX + octaveOffset + kNoteX[n];
  int y = mMiddleCY;
  int w = kNoteWidth[n];
  int h = kNoteHeight[n];

  if (isBlack(n))
    g.fillRect(x, y, w, h);
  else
    g.drawRect(x, y, w, h);
}

private void drawSelection(Graphics g, int note) {
  int n = note % 12;
  int octaveOffset = ((note - n) / 12 - 5) * 7 * kNoteWidth[0];
  int x = mMiddleCX + octaveOffset + kNoteX[n];
  int y = mMiddleCY;
  int w = kNoteWidth[n];
  int h = kNoteHeight[n];
```

```
    int sw = 6;
    int sx = x + (w - sw) / 2;
    int sy = y + h - 8;
    g.setColor(0xffffff);
    g.fillRect(sx, sy, sw, sw);
    g.setColor(0x000000);
    g.drawRect(sx, sy, sw, sw);
    g.drawLine(sx, sy, sx + sw, sy + sw);
    g.drawLine(sx, sy + sw, sx + sw, sy);
  }

  private boolean isBlack(int note) {
    return kBlack[note];
  }

  public void keyPressed(int keyCode) {
    int action = getGameAction(keyCode);
    switch (action) {
      case LEFT:
        mCurrentNote--;
        if (mCurrentNote < 60)
          mCurrentNote = 60;
        repaint();
        break;
      case RIGHT:
        mCurrentNote++;
        if (mCurrentNote > 72)
          mCurrentNote = 72;
        repaint();
        break;
      case FIRE:
        try { Manager.playTone(mCurrentNote, 1000, 100); }
        catch (MediaException me) {}
        break;
      default:
        break;
    }
  }
}
```

The ABB also offers support for playing sampled audio files, although the specification does not require support for this feature. To play sampled audio, you just need to get a `Player` for the data you wish to hear, and then start the `Player` running. You can get a `Player` by asking `Manager` for one. In its simplest form, playing sampled audio data looks like this:

```
URL url = "http://65.215.221.148:8080/wj2/res/relax.wav";
Player p = Manager.createPlayer(url);
p.start();
```

In this approach, the web server provides the content type of the data. Another approach is to obtain an `InputStream` to the audio data, and then create a `Player` by telling `Manager` the content type of the data. This is handy for reading audio files that are stored as resources in the MIDlet suite JAR. For example:

```
InputStream in = getClass().getResourceAsStream("/relax.wav");
Player player = Manager.createPlayer(in, "audio/x-wav");
player.start();
```

Listing 16-2 is a simple MIDlet that demonstrates both techniques.

Listing 16-2. *Playing Audio Files*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
import javax.microedition.media.*;

public class AudioMIDlet
    extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;
  private List mMainScreen;

  public void startApp() {
    mDisplay = Display.getDisplay(this);

    if (mMainScreen == null) {
      mMainScreen = new List("AudioMIDlet", List.IMPLICIT);

      mMainScreen.append("Via HTTP", null);
      mMainScreen.append("From resource", null);
      mMainScreen.addCommand(new Command("Exit", Command.EXIT, 0));
      mMainScreen.addCommand(new Command("Play", Command.SCREEN, 0));
      mMainScreen.setCommandListener(this);
    }

    mDisplay.setCurrent(mMainScreen);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}
```

```
public void commandAction(Command c, Displayable s) {
  if (c.getCommandType() == Command.EXIT) notifyDestroyed();
  else {
    Form waitForm = new Form("Loading...");
    mDisplay.setCurrent(waitForm);
    Thread t = new Thread(this);
    t.start();
  }
}

public void run() {
  String selection = mMainScreen.getString(
      mMainScreen.getSelectedIndex());
  boolean viaHttp = selection.equals("Via HTTP");

  if (viaHttp)
    playViaHttp();
  else
    playFromResource();
}

private void playViaHttp() {
  try {
    String url = getAppProperty("AudioMIDlet-URL");
    Player player = Manager.createPlayer(url);
    player.start();
  }
  catch (Exception e) {
    showException(e);
    return;
  }
  mDisplay.setCurrent(mMainScreen);
}

private void playFromResource() {
  try {
    InputStream in = getClass().getResourceAsStream("/relax.wav");
    Player player = Manager.createPlayer(in, "audio/x-wav");
    player.start();
  }
  catch (Exception e) {
    showException(e);
    return;
  }
  mDisplay.setCurrent(mMainScreen);
}
```

```
  private void showException(Exception e) {
    Alert a = new Alert("Exception", e.toString(), null, null);
    a.setTimeout(Alert.FOREVER);
    mDisplay.setCurrent(a, mMainScreen);
  }
}
```

To play the audio file over the Internet, you will need to set up the MIDlet property `AudioMIDlet-URL` to have the following value:

```
http://65.215.221.148:8080/wj2/res/relax.wav
```

Playing MP3 Music

If your device supports the playback of MP3 music through MMAPI, the `AudioMIDlet` presented previously can be used to play MP3 music that is retrieved using HTTP by simply changing the `AudioMIDlet-URL` property to refer to an MP3 file. For example:

```
http://65.215.221.148:8080/wj2/res/mytrack.mp3
```

When you want to play an MP3 soundtrack from a resource file, you will need to change the following line in the `playFromResource()` method:

```
InputStream in = getClass().getResourceAsStream("/mytrack.mp3");
Player player = Manager.createPlayer(in, "audio/mpeg");
```

While the HTTP protocol enables the server to set the `content`, you must set the type explictly when playing back from a resource file. The content type string for MP3 is "audio/mpeg". (See `http://www.iana.org/assignments/media-types/` for more types.) The next section explores `content type` further.

■ **Note** Playback of MP3 files is not a mandatory requirement of MIDP or JTWI 1.0. In general, device manufacturers must pay additional licensing fees to implement MP3 playback. If your application or game needs to be usable across a variety of devices, it is wise not to have dependency on MP3 playback.

MMAPI Media Concepts

Audio data comes in a variety of *content types*. A content type is really just a file format, a specification that tells how each bit in the data contributes to the resulting sound. Common audio content types are MP3, AIFF, and WAV. In the MIDP 2.0 ABB, content types are specified using MIME types, which use a string to specify a primary and secondary type. For example, the MIME type for WAV audio is "audio/x-wav".

The content type tells how to translate bits into sound, but that's only half the battle. A *protocol* specifies how to get the data from its original location to the place where it will be rendered. You could use HTTP, for example, to transfer audio data from a server to a MIDP device.

In the ABB, a `Player` knows how to render audio data with a particular content type, while an associated *data source* handles transporting the data to the `Player`. In the Mobile Media API, the abstract `DataSource` class represents data sources. In the MIDP 2.0 ABB, data sources are not explicitly available, but implicitly associated with a `Player`. The path of the audio information is illustrated in Figure 16-2.

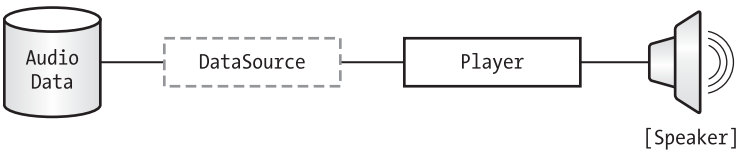


Figure 16-2. *Audio data path*

`Manager` doles out `Players` for content types and protocols requested via its `createPlayer()` methods. One or more *controls* may be associated with a `Player` to specify playback parameters like volume. In the ABB, `javax.microedition.media.Control` is an interface representing a control, while the `javax.microedition.media.control` package contains more specific subinterfaces. The relationship between the classes is shown in Figure 16-3.

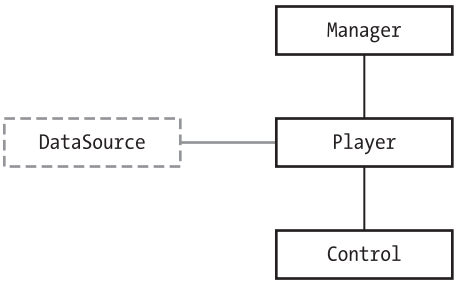


Figure 16-3. *Class relationships*

Supported Content Types and Protocols

One of the least understood aspects of the ABB is its supported content types. MIDP 2.0 is very flexible about the content types and protocols an implementation may support. All the specification says is that if sampled audio is supported at all, then 8-bit PCM WAV must be supported. Beyond that, the sky's the limit.

If you do ask `Manager` for data or a protocol that it can't handle, a `MediaException` will be thrown.

You can find out, at runtime, what content types and protocols are supported using two methods in the `Manager` class:

```
public static String [] getSupportedContentTypes(String protocol)
public static String [] getSupportedProtocols(String content_type)
```

You can find out the content types for a given protocol, or the protocols for a given content. If you supply `null` to either of these methods, you'll get a complete list of supported content types or protocols.

The MIDlet in Listing 16-3 finds all supported content types and prints out the corresponding protocols for each.

Listing 16-3. *Examining Content Types and Protocols at Runtime*

```
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
import javax.microedition.media.*;

public class MediaInformationMIDlet
    extends MIDlet
    implements CommandListener {
  private Form mInformationForm;

  public void startApp() {
    if (mInformationForm == null) {
      mInformationForm =
          new Form("Content types and protocols");
      String[] contentTypes =
          Manager.getSupportedContentTypes(null);
      for (int i = 0; i < contentTypes.length; i++) {
        String[] protocols =
            Manager.getSupportedProtocols(contentTypes[i]);
        for (int j = 0; j < protocols.length; j++) {
          StringItem si = new StringItem(contentTypes[i] + ": ",
              protocols[j]);
          si.setLayout(Item.LAYOUT_NEWLINE_AFTER);
          mInformationForm.append(si);
        }
      }
      Command exitCommand = new Command("Exit", Command.EXIT, 0);
      mInformationForm.addCommand(exitCommand);
      mInformationForm.setCommandListener(this);
    }

    Display.getDisplay(this).setCurrent(mInformationForm);
  }

  public void pauseApp() {}

  public void destroyApp(boolean unconditional) {}

  public void commandAction(Command c, Displayable s) {
    notifyDestroyed();
  }
}
```

Figure 16-4 shows the results if you run `MediaInformationMIDlet` on the J2ME Wireless Toolkit emulator (in the 2.0 beta 2 release). There are three things to understand about this list:

1. HTTP is a file transfer protocol, not a streaming media protocol. If you specify a media file with HTTP, the whole file will be downloaded before playback begins. By contrast, some devices may support real streaming protocols like RTP (see `http://www.ietf.org/rfc/rfc1889.txt`).

2. The "audio/x-tone-seq" content type is not really sampled audio; it's a special case for tone sequences, which we'll describe soon.

3. The list includes some features and content types (video, MIDI, audio capture) from the wireless toolkit's MMAPI implementation. If you want to see a bare-bones list of supported content types and protocols, turn off the MMAPI support as described later, in the section entitled "The Mobile Media API."

Figure 16-4. *MediaInformationMIDlet running on the toolkit's 2.0 beta2 emulator*

To find out the content type of an existing `Player`, just call `getContentType()`.

Player Life Cycle

Because playing audio may use scarce resources on a MIDP device, and because sampled audio files are relatively large, `Player` has a detailed life cycle that allows its behavior to be closely controlled. The life cycle is described in terms of *states*, represented by constants in the `Player` interface. The usual order of states in the `Player`'s life cycle is as follows:

A `Player` begins its life as `UNREALIZED`. This means that a `Player` implementation has been created, but it hasn't tried to find the audio data it's supposed to render, and it hasn't tried to acquire resources like the audio hardware.

A `Player` becomes `REALIZED` after it locates the media data, for example, by initiating a network connection and sending headers.

The next state, PREFETCHED, means the Player has done everything else it needed to do to get ready to start rendering audio. This might include obtaining control of the audio hardware, filling up buffers, or other operations.

When the Player has begun rendering audio data, it is in the STARTED state.

One final state, CLOSED, indicates that the Player has released all resources, shut down all network connections, and cannot be used again.

Player contains a corresponding set of methods that move from state to state:

```
public void prefetch()
public void realize()
public void start()
```

These methods work as you'd expect, for the most part. If you skip a step, the intervening states are implied. In the preceding example, we call start() on a freshly created Player, which implies calls to prefetch() and realize().

If anything goes wrong with locating the media data or acquiring system resources, these methods throw a MediaException.

Several other methods allow for backward state transitions, although their names are not as intuitive. The stop() method takes a STARTED Player back to PREFETCHED. The deallocate() method moves a PREFETCHED or STARTED Player back to the REALIZED state by releasing resources. The deallocate() method has one additional wrinkle; it will take an UNREALIZED Player that is stuck trying to locate its media (in the middle of realize()) back to the UNREALIZED state.

Finally, the close() method moves a Player in any state to CLOSED. All resources are released, all network connections are closed, and the Player cannot be used again.

You may retrieve the Player's current state by calling getState().

Now that you understand Player's life cycle, you can probably imagine ways to improve on the simple AudioMIDlet presented previously. You might, for example, call prefetch() on the newly created Player to ensure that playback could begin as soon as possible after the user selects the Play command. You might not have noticed much of delay, but a real device will perform much slower:

- Your desktop computer running the emulator has a lot more processing power and memory than a MIDP device.
- The emulator on your desktop probably has a much faster network connection than a real MIDP device.
- The file relax.wav that is used by AudioMIDlet is very small (1530 bytes). A larger media file would produce more noticeable delays.

As with network and persistent storage operations, any time-consuming operations with a Player should be performed in a thread that is separate from the user interface thread. Although the start() method does not block, both realize() and prefetch() will not return until they have finished their potentially slow work.

Controlling Players

A Player's *media time* is its current position in the audio playback. For example, a Player that is halfway through a 4-second audio clip would have a media time of 2,000,000 microseconds.

If you want to jump to a particular point in an audio clip, call `setMediaTime()`.You can find out the current media time using `getMediaTime()`. The total time represented by the audio clip is returned from `getDuration()`. For some types of streaming media, the duration cannot be determined, in which case the special value `TIME_UNKNOWN` will be returned.

`Players` can also loop, which means the audio clip is played over and over again. You can control this behavior by calling `setLoopCount()` before the `Player` is started. Pass a value of `-1` to loop indefinitely.

Beyond the `Player` interface is a whole world of `Controls`. You can obtain a list of `Controls` for a `Player` by calling `getControls()` (a method `Player` inherits from the `Controllable` interface). This method returns an array of `Controls` that are appropriate for the `Player`. The ABB only defines a `VolumeControl` and a `ToneControl`, but implementations are free to provide other controls appropriate for the content types and protocols they support.

To obtain just one control, pass its name to `Player`'s `getControl()` method (again inherited from `Controllable`). The name is the name of an interface in the `javax.microedition.media.control` package.

The `Player` must be in at least a `REALIZED` state to return its controls.

To use a `VolumeControl` to set playback volume to half its maximum, for example, you would do something like this:

```
// Player player = Manager.createPlayer(...);
player.prefetch();
VolumeControl vc = (VolumeControl)player.getControl("VolumeControl");
vc.setLevel(50);
```

Listening for Player Events

`Player` includes methods for adding and removing listeners that will be notified about various milestones in the `Player`'s life:

```
public void addPlayerListener(PlayerListener playerListener)
public void removePlayerListener(PlayerListener playerListener)
```

`PlayerListener` defines a single method that is called with a variety of informational messages:

```
public void playerUpdate(Player player, String event, Object eventData)
```

The `player` parameter, of course, is the `Player` generating the event. The event is described by a string, `event`, and may include additional information, `eventData`. Constants in the `PlayerListener` interface describe common events: `STARTED`, `END_OF_MEDIA`, and `VOLUME_CHANGED` are a few. See the API documentation for the full list.

Tones and Tone Sequences

You've already seen how easy it is to play single tones using `Manager`. There's a somewhat more sophisticated tone sequence player lurking in the MIDP 2.0 media APIs. It's implemented within the `Player` and `Control` architecture, which is kind of a kluge, considering that tone sequences have little in common with sampled audio.

To obtain the tone sequence `Player`, just pass a special value (`Manager`'s `TONE_DEVICE_LOCATOR`) to `createPlayer()`. If you examine `TONE_DEVICE_LOCATOR`, you'll see it is

the value "device://tone", which kind of means a "device" protocol and an "audio/x-tone-seq" content type. You may remember seeing this in the output of `MediaInformationMIDlet`. As we said, it's kind of a kluge.

Once you've obtained the tone sequence `Player`, you can give it a tone sequence using its associated `ToneControl` object. To get this control, call `getControl("ToneControl")`. (Remember, the `Player` needs to be `REALIZED` first.)

`ToneControl` encapsulates a byte array whose syntax and construction is obtusely described in the API documentation. Master it and you'll be able to make any song into a monophonic masterpiece, Bobby McFerrin style. We'll describe the byte array format and present several examples.

The tones themselves are defined with note number and duration pairs. Note numbers are the same as for `Manager`'s `playTone()` method, where 60 is middle C and 69 is the 440-Hz A above middle C. Duration is specified as multiples of the *resolution*. By default, the resolution of a tone sequence is 1/64 of one measure of 4/4 time (four beats). Therefore, a duration of 64 corresponds to a whole note (four beats), 16 corresponds to a quarter note (one beat), 8 is an eighth note, and so on.

All tone sequences must begin with a version. This is not the version of your data, but rather the version of the tone sequence format you're using. Currently the only accepted version is 1. A simple tone sequence looks like this:

```
byte[] sequence = new byte[] {
  ToneControl.VERSION, 1,
  67, 16, // The
  69, 16, // hills
  67,  8, // are
  65,  8, // a -
  64, 48, // live
  62,  8, // with
  60,  8, // the
  59, 16, // sound
  57, 16, // of
  59, 32, // mu -
  59, 32  // sic
};
```

This tone sequence relies on several default values. The default tempo is 120 beats per minute (bpm) and the default resolution is 1/64. The default volume is 100 (the loudest).

Other features are available in tone sequences. A reasonable amount of control is possible:

- Set the tempo by using the `TEMPO` constant and passing the tempo, in beats per minute, divided by four. For example, `ToneControl.TEMPO, 15` sets the tempo to 60 bpm, or one beat per second. This may be done only once at the beginning of a sequence (following the `VERSION`).

- The resolution can be changed from its default of 1/64 using the `RESOLUTION` constant. The argument that is passed is the denominator, for example, using `ToneControl.RESOLUTION, 64` will restore the default resolution of 1/64. This may be done only once at the beginning of a sequence (following the `TEMPO`).

- Reusable *blocks* of tones can be defined. To begin a block definition, use `ToneControl.BLOCK_START` and supply a block number. Then supply the notes and durations that go into the block. To end a block definition, use `ToneControl.BLOCK_END` and supply the same block number. To actually play a block, use `ToneControl.PLAY_BLOCK` and supply the number of the block you wish to play. Blocks must be defined following the `VERSION`, `TEMPO`, and `RESOLUTION` in a sequence.
- The volume can be set at any time during a sequence for dramatic dynamic effects. For example, `ToneControl.SET_VOLUME, 25` sets the volume to one quarter of its maximum value.
- To indicate a rest of a certain duration, use the special note value `ToneControl.SILENCE`.
- You can repeat a single note multiple times. For example, `ToneControl.REPEAT, 7, 60, 16` plays middle C (60) seven times with a duration of 16.

The MIDlet in Listing 16-4 contains several examples that will help you write your own tone sequences.

Listing 16-4. *Old Classics in Monophonic Glory*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
import javax.microedition.media.*;
import javax.microedition.media.control.*;

public class ToneMIDlet
    extends MIDlet
    implements CommandListener {
  private final static String kSoundOfMusic = "Sound of Music";
  private final static String kQuandoMenVo = "Quando men vo";
  private final static String kTwinkle = "Twinkle number VII";

  private Display mDisplay;
  private List mMainScreen;

  public void startApp() {
    mDisplay = Display.getDisplay(this);

    if (mMainScreen == null) {
      mMainScreen = new List("AudioMIDlet", List.IMPLICIT);
```

```
    mMainScreen.append(kSoundOfMusic, null);
    mMainScreen.append(kQuandoMenVo, null);
    mMainScreen.append(kTwinkle, null);
    mMainScreen.addCommand(new Command("Exit", Command.EXIT, 0));
    mMainScreen.addCommand(new Command("Play", Command.SCREEN, 0));
    mMainScreen.setCommandListener(this);
  }

  mDisplay.setCurrent(mMainScreen);
}

public void pauseApp() {}

public void destroyApp(boolean unconditional) {}


public void commandAction(Command c, Displayable s) {
  if (c.getCommandType() == Command.EXIT) notifyDestroyed();
  else run();
}

public void run() {
  String selection = mMainScreen.getString(
      mMainScreen.getSelectedIndex());

  byte[] sequence = null;
  if (selection.equals(kSoundOfMusic)) {
    sequence = new byte[] {
      ToneControl.VERSION, 1,
      67, 16, // The
      69, 16, // hills
      67,  8, // are
      65,  8, // a -
      64, 48, // live
      62,  8, // with
      60,  8, // the
      59, 16, // sound
      57, 16, // of
      59, 32, // mu -
      59, 32  // sic
    };
  }
```

```
else if (selection.equals(kQuandoMenVo)) {
  sequence = new byte[] {
    ToneControl.VERSION, 1,
    ToneControl.TEMPO, 22,
    ToneControl.RESOLUTION, 96,
    64, 48, ToneControl.SILENCE, 8, 52, 4, 56, 4, 59, 4, 64, 4,
    63, 48, ToneControl.SILENCE, 8, 52, 4, 56, 4, 59, 4, 63, 4,
    61, 72,
    ToneControl.SILENCE, 12, 61, 12,
        63, 12, 66, 2, 64, 10, 63, 12, 61, 12,
    64, 12, 57, 12, 57, 48,
    ToneControl.SILENCE, 12, 59, 12,
        61, 12, 64, 2, 63, 10, 61, 12, 59, 12,
    63, 12, 56, 12, 56, 48,
  };
}

else if (selection.equals(kTwinkle)) {
  sequence = new byte[] {
    ToneControl.VERSION, 1,
    ToneControl.TEMPO, 22,
    ToneControl.BLOCK_START, 0,
    60, 8,        62, 4, 64, 4, 65, 4, 67, 4, 69, 4, 71, 4,
    72, 4, 74, 4, 76, 4, 77, 4, 79, 4, 81, 4, 83, 4, 84, 4,
    83, 4, 81, 4, 80, 4, 81, 4, 86, 4, 84, 4, 83, 4, 81, 4,
    81, 4, 79, 4, 78, 4, 79, 4, 60, 4, 79, 4, 88, 4, 79, 4,
    57, 4, 77, 4, 88, 4, 77, 4, 59, 4, 77, 4, 86, 4, 77, 4,
    56, 4, 76, 4, 86, 4, 76, 4, 57, 4, 76, 4, 84, 4, 76, 4,
    53, 4, 74, 4, 84, 4, 74, 4, 55, 4, 74, 4, 83, 4, 74, 4,
    84, 16, ToneControl.SILENCE, 16,
    ToneControl.BLOCK_END, 0,
    ToneControl.BLOCK_START, 1,
    79, 4, 84, 4, 88, 4, 86, 4, 84, 4, 83, 4, 81, 4, 79, 4,
    77, 4, 76, 4, 74, 4, 72, 4, 71, 4, 69, 4, 67, 4, 65, 4,
    64, 8,        76, 8,        77, 8,        78, 8,
    79, 12,             76, 4, 74, 8, ToneControl.SILENCE, 8,
    ToneControl.BLOCK_END, 1,

    ToneControl.SET_VOLUME, 100, ToneControl.PLAY_BLOCK, 0,
    ToneControl.SET_VOLUME,  50, ToneControl.PLAY_BLOCK, 0,
    ToneControl.SET_VOLUME, 100, ToneControl.PLAY_BLOCK, 1,
    ToneControl.SET_VOLUME,  50, ToneControl.PLAY_BLOCK, 1,
    ToneControl.SET_VOLUME, 100, ToneControl.PLAY_BLOCK, 0,
  };
}
```

```
    try {
      Player player = Manager.createPlayer(Manager.TONE_DEVICE_LOCATOR);
      player.realize();
      ToneControl tc = (ToneControl)player.getControl("ToneControl");
      tc.setSequence(sequence);
      player.start();
    }
    catch (Exception e) {
      Alert a = new Alert("Exception", e.toString(), null, null);
      a.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(a, mMainScreen);
    }
  }
}
```

Remember, `Player`'s `start()` method does not block. If you want, you can start all three songs running simultaneously in the emulator. This works because the toolkit emulator is using a polyphonic device to play the tone sequences. On a real device, playing multiple sequences simultaneously is probably not possible. But you can set one sequence running, and assuming it doesn't suck up too much processor time, your MIDlet can go and do other tasks, like drawing a game display or connecting to a network.

The Mobile Media API

MIDP audio support is only a subset of the full power of the Mobile Media API. If you're using the J2ME Wireless Toolkit, its emulators support the full MMAPI by default. This means that you have other APIs available and several additional content types supported by the implementation.

If you'd like to remove MMAPI support, leaving only MIDP audio, click the *Settings* button from KToolbar; this will display the API Selection tab. You can uncheck the Mobile Media API (JSR 135) if you do not wish to use it.

Playing Video Using the MMAPI

You already know most of the concepts needed to play video on your phone. The great thing about the design of the MMAPI is that you can use the exact same approach to play video, as you have with audio.

You need to create a player, realize it, and then call `start()` on it to play video. These are the same steps as in the playback of audio. Only the content type and file extension change.

The `VideoMIDlet` code in Listing 16-5 is a modified version of the `AudioMIDlet` presented earlier. In this case, `VideoMIDlet` plays a MPEG1 video file, called `fish.mpg`, from the resource.

Look back at `AudioMIDlet`, compare the player creation code in the `playFromResource()` method of Listing 16-5:

```
InputStream in = getClass().getResourceAsStream("/fish.mpg");
mPlayer = Manager.createPlayer(in, "video/mpeg");
```

The only change is the content type, now "video/mpeg"; and the file name, now "/fish.mpg".

Displaying the Video

Unlike audio, which is played back through the speakers, video will take up some space on the user interface. MMAPI makes this quite simple. You have two choices:

- Display the video on a custom `Canvas`.
- Display the video as an `Item` within a `Form`.

In either case, you must first get hold of a `VideoControl` instance. You do this the same way you'd get a `VolumeControl` or `ToneControl` from an audio player:

```
(VideoControl) vidc = (VideoControl)  player.getControl("VideoControl");
```

Once you have this `VideoControl` instance, you can create either your custom `Canvas` class or a video `Item` for form-based display.

Video on Custom Canvas

If you want to display the video on a custom `Canvas`, you need to derive a class from `Canvas`. Say that your class is called `VideoCanvas`; the following code in the constructor will position and display the video:

```
public VideoCanvas(VideoControl videoControl) {

  videoControl.initDisplayMode(
      VideoControl.USE_DIRECT_VIDEO, this);

  try {
    videoControl.setDisplayLocation(5, 5);
    videoControl.setDisplaySize(getWidth()- 10, getHeight ()- 10);
  }
  catch (MediaException ex) {
  ....
  }
  videoControl.setVisible(true);
}
```

Note that you need to pass in the `VideoControl` instance during construction. The video display is created using the `initDisplayMode()` method, and the mode `VideoControl.USE_DIRECT_VIDEO` indicates to the `VideoControl` that you are working within a `Canvas` subclass. In this case, the video display takes up the entire `VideoCanvas`, with a 5-pixel border on all four sides.

Video on an Item Within a Form

Using an `Item` to display the video allows you to mix the video with other `Items` on a `Form`. The `VideoMIDlet` code in Listing 16-5 uses this approach. You can obtain an `Item` instance by calling the `initDisplayMode()` method using a mode of `VideoControl.USE_GUI_PRIMITIVE`:

```
(Item) mVideoItem = (Item)   mVideoControl.initDisplayMode(
          VideoControl.USE_GUI_PRIMITIVE, null);
mForm.append(mVideoItem);
```

The resulting `Item` can be immediately added to a form. Figure 16-5 shows `VideoMIDlet` running on the WTK emulator.

Figure 16-5. *Playing video with MMAPI*

■ **Tip** The most common video content type supported by MMAPI is "video/mpeg" or MPEG-1 video. This is often called the VideoCD (VCD) format. It is the predecessor of MPEG-2, which is used in today's DVD products. While lower in resolution, MPEG-1 is more than adequate for the screen size found in today's mobile device. You can convert your video to MPEG-1 format easily using a variety of tools. An excellent free one can be found here: `http://www.tmpgenc.net/`.

Listing 16-5. *Playing Video Using MMAPI*

```
import java.io.*;
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
import javax.microedition.media.*;
import javax.microedition.media.control.*;
```

```
public class VideoMIDlet
extends MIDlet
implements CommandListener, Runnable {
    private Display mDisplay;
    private Form mMainScreen;
    private Item mVideoItem;
    private VideoControl mVidc;
    private Command mPlayCommand;
    private Player mPlayer = null;


    public void startApp() {
        mDisplay = Display.getDisplay(this);

        if (mMainScreen == null) {
            mMainScreen = new Form("Video MIDlet");
            mMainScreen.addCommand(new Command("Exit", Command.EXIT, 0));
            mPlayCommand = new Command("Play", Command.SCREEN, 0);
            mMainScreen.addCommand(mPlayCommand);
            mMainScreen.setCommandListener(this);
        }

        mDisplay.setCurrent(mMainScreen);
    }

    public void pauseApp() {}

    public void destroyApp(boolean unconditional) {
        if (mPlayer != null)  {
                mPlayer.close();
        }

    }

    public void commandAction(Command c, Displayable s) {
        if (c.getCommandType() == Command.EXIT) {
            destroyApp(true);
            notifyDestroyed();
        }
        else {
            Form waitForm = new Form("Loading...");
            mDisplay.setCurrent(waitForm);
            Thread t = new Thread(this);
            t.start();
        }
    }
```

```
    public void run() {
        playFromResource();
    }


    private void playFromResource() {
        try {
            InputStream in = getClass().getResourceAsStream("/fish.mpg");
            mPlayer = Manager.createPlayer(in, "video/mpeg");

            mPlayer.realize();
            if ((mVidc = (VideoControl)
                              mPlayer.getControl("VideoControl")) != null) {
                mVideoItem = (Item)
                 mVidc.initDisplayMode(VideoControl.USE_GUI_PRIMITIVE, null);
                mMainScreen.append(mVideoItem);
            }

            mPlayer.start();
            mMainScreen.removeCommand(mPlayCommand);
            mDisplay.setCurrent(mMainScreen);
        }
        catch (Exception e) {
            showException(e);
            return;
        }
    }

    private void showException(Exception e) {
        Alert a = new Alert("Exception", e.toString(), null, null);
        a.setTimeout(Alert.FOREVER);
        mDisplay.setCurrent(a, mMainScreen);

    }

}
```

Snapping Pictures on a Camera Phone

An expensive executive toy in the past, cell phones with built-in cameras are now commonplace and inexpensive. MMAPI offers your application access to the camera's picture taking ability.

The model is quite simple: the camera acts as a video player. The video displayed by this player will be the live action that the camera is viewing. At any time after the player starts, you can use the `VideoControl` to snap a still picture of the video.

If your camera phone has MMAPI support, you will be able to access it as a player using the URL "capture://video":

```
Player  mPlayer = Manager.createPlayer("capture://video");
```

You can then obtain a `VideoControl` instance from the player. This `VideoControl` can be used to show the live video on either a `Canvas` subclass or an `Item` within a form (shown in the previous section). At any time, you can capture a still picture by calling the `getSnapshot()` method of the `VideoControl`. You can specify a graphic format as a parameter (format supported depends on implementation), or use null to obtain the default (always supported) PNG format:

```
byte[] rawImg = mVidc.getSnapshot(null);
```

The returned `byte` array contains the raw image. This `byte` array can be converted to an `Image` using the call to `Image`'s static factory method:

```
Image image = Image.createImage(rawImg, 0, rawImg.length);
```

WTK 2.x Camera Simulation

When using an emulator from the Wireless Toolkit, camera support in MMAPI is performed via simulated incoming video. The WTK does not support access to the underlying platform's video capture capability. This simplifies WTK maintenance and allows MMAPI snapshots to work over any platform, with or without camera support.

The simulated incoming video has a moving grid, with a seconds counter on the top left. This image ensures that every video frame is different from all the subsequent ones.

Listing 16-6 shows `CameraMIDlet`, which can be used to take snapshots using a camera phone. Figure 16-6 shows `CameraMIDlet` running on the emulator, with simulated camera video. The live video is displayed as an `Item` at the top of the form. You can click the Capture menu item, and a picture of the live video will be snapped and displayed below the video using an `ImageItem`.

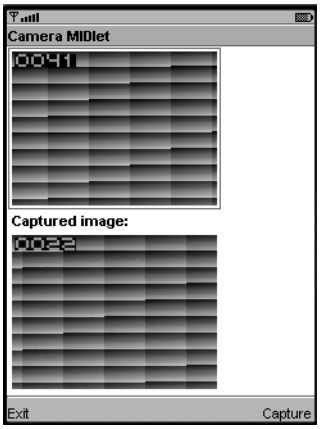


Figure 16-6. *Capturing images using simulated video on the WTK emulator*

Listing 16-6. *Capturing Images Using Your Camera Phone*

```
import java.io.*;
import javax.microedition.io.*;
import javax.microedition.lcdui.*;
import javax.microedition.midlet.*;
import javax.microedition.media.*;
import javax.microedition.media.control.*;

public class CameraMIDlet
extends MIDlet
implements CommandListener, Runnable {
    private Display mDisplay;
    private Form mMainScreen;
    private Item mVideoItem;
    private VideoControl mVidc;
    private Command mCaptureCommand;
    Image mQMarkImg = null;
    private ImageItem mCapturedImgItem = null;
    private Player mPlayer = null;
    private boolean mEndNow = false;

    public void startApp() {
        mDisplay = Display.getDisplay(this);
        if (mQMarkImg == null)  {
            try {
               mQMarkImg = Image.createImage("/qmark.png");
              } catch (Exception ex) {
                showException(ex);
            }
        }
        if (mMainScreen == null) {
            mMainScreen = new Form("Camera MIDlet");
            mMainScreen.addCommand(new Command("Exit", Command.EXIT, 0));
            mCaptureCommand = new Command("Capture", Command.SCREEN, 0);
            mMainScreen.addCommand(mCaptureCommand);
            mMainScreen.setCommandListener(this);
        }

        mDisplay.setCurrent(mMainScreen);
            Thread t = new Thread(this);
            t.start();
            mEndNow = false;
    }

    public void pauseApp() {}
```

```
    public void destroyApp(boolean unconditional) {

        if (mPlayer != null)  {
            mPlayer.close();
        }
        mEndNow = true;
        synchronized(this) {
          this.notify();
        }
    }

    public void commandAction(Command c, Displayable s) {
        if (c.getCommandType() == Command.EXIT) {
            destroyApp(true);
            notifyDestroyed();
        }
        else {
            // Capture
           synchronized(this) {
               this.notify();
           }
        }
    }

    public void run() {
        viewCamera();
        while(!mEndNow) {
            synchronized(this) {
                try {
                this.wait();
                } catch (InterruptedException ex) {
                    // Ignore
                }
               if (!mEndNow)
                try {
                byte[] rawImg = mVidc.getSnapshot(null);
                Image image = Image.createImage(rawImg, 0, rawImg.length);
                mCapturedImgItem.setImage(image);
                } catch (MediaException ex) {
                   continue;
                }

            }

        }
    }
```

```
    private void viewCamera() {
        try {
            mPlayer = Manager.createPlayer("capture://video");
            mPlayer.realize();
            if ((mVidc = (VideoControl)
                            mPlayer.getControl("VideoControl")) != null) {
                mVideoItem = (Item)
                mVidc.initDisplayMode(VideoControl.USE_GUI_PRIMITIVE, null);
                int prefLayout = Item.LAYOUT_2 | Item.LAYOUT_LEFT |
                    Item.LAYOUT_NEWLINE_AFTER;
                mVideoItem.setLayout(prefLayout);
                mCapturedImgItem =
                new ImageItem("", mQMarkImg, prefLayout, "");
               StringItem lab = new StringItem("Captured image:", "");
               lab.setLayout(prefLayout);

                mMainScreen.append(mVideoItem);
                mMainScreen.append(lab);
                mMainScreen.append(mCapturedImgItem);
            }

            mPlayer.start();
            mDisplay.setCurrent(mMainScreen);
        }
        catch (Exception e) {
            showException(e);
            return;
        }
    }

    private void showException(Exception e) {
        Alert a = new Alert("Exception", e.toString(), null, null);
        a.setTimeout(Alert.FOREVER);
        mDisplay.setCurrent(a, mMainScreen);
       }
}
```

Summary

In this chapter, you learned about playing tones and sampled audio in MIDP. It utilized a subset of the Mobile Media API (MMAPI), the Audio Building Block (ABB). It is based on `Player`s that know how to render audio data and implicit protocol objects that understand how to transport audio data to the `Player`. Aside from optional and flexible support for sampled audio, the ABB also includes a tone sequence player. In MMAPI, the same familiar `Player` and `Control` API model is used to display video and to snap pictures on a camera phone. Your MIDlets can now benefit from the excitement of music, sampled audio, and recorded video.

CHAPTER 17

Performance Tuning

MIDP is a small platform. The processor on a MIDP device will probably be much slower than a typical desktop computer processor, and the available memory will be much smaller also. Making your application run fast and lean is important. You'll need to use memory sparingly, make your application run fast enough to be easily usable, and structure it so that the code itself is as small as it can be.

This chapter describes simple methods for benchmarking your existing code. It then goes on to describe various optimizations that can make your code run faster or use less memory. Common sense will take you a long way, but this chapter is devoted to giving you the basic techniques for optimizing your application.

The important rule of thumb is this: only optimize where it's needed. Said another way: if it ain't broke, don't fix it. We suggest that your first pass at coding your application should concentrate on cleanliness and maintainability. If performance problems exist, identify them and begin optimizing. You shouldn't be optimizing code as you write it—that's just likely to result in hard-to-read, hard-to-maintain code. Write first, then test, then optimize.

Benchmarking

In the J2SE world, developers have many tools for examining the performance of code, the location of bottlenecks, and memory usage. Unfortunately, little of this is available in the J2ME world. For the most part, you'll have to perform benchmarking the old-fashioned way. For this, there are several methods in the MIDP API that will be useful. To test memory use, you can use the following methods in `java.lang.Runtime`:

```
public long freeMemory()
public long totalMemory()
```

The first method tells how much memory, in bytes, is currently available. The second method gives the total number of bytes in the current runtime environment, whether they are used for objects or not. Interestingly, this number can change because the host environment (device operating system) can give more memory to the Java runtime environment.

To find out how much memory an object uses, you can do something like this:

```
Runtime runtime = Runtime.getRuntime();
long before, after;
System.gc();
before = runtime.freeMemory();
Object newObject = new String();
after = runtime.freeMemory();
long size = before - after;
```

Aside from examining memory usage, you may also be concerned with the speed of your application. Again, you can test this the old-fashioned way—look at the clock before you start doing something, and then look at it again when you're finished. The relevant method comes from the `java.lang.System` class:

```
public static long currentTimeMillis()
```

You might calculate the execution time for a method like this:

```
long start, finish;
start = System.currentTimeMillis();
someMethod();
finish = System.currentTimeMillis();
long duration = finish - start;
```

For accurate timing, you should measure the duration multiple times and calculate an average.

Diagnostic Tools in the J2ME Wireless Toolkit

WTK 2.x contains three tools you can use to understand your application's performance characteristics.

The first tool is a memory monitor. You can see a graph of memory usage in your application over time or a detailed breakdown of every object in your application. Turn on the memory monitor by choosing Edit ➤ Preferences from the KToolbar menu. Click the Monitoring tab and check off Enable Memory Monitor. Next time you run the emulator, an additional window will pop up. You can examine the total memory used, which is useful when you're trying to make an application fit on a device with a limited heap size. (You can even set the heap size of the emulator in the Storage tab of the preferences window.) Figure 17-1 shows the memory monitor graph.You can click any column in the table to sort by that column. You can even search for specific items using View ➤ Find. Examining the memory monitor window will help you identify the places where memory is consumed most in your application.

Aside from the memory monitor, the toolkit also includes a *code profiler*—a tool that shows how much time is spent in every method in your application. To turn on the profiler, choose Edit ➤ Preferences from the KToolbar menu. Choose the Monitoring tab and check off Enable Profiling.

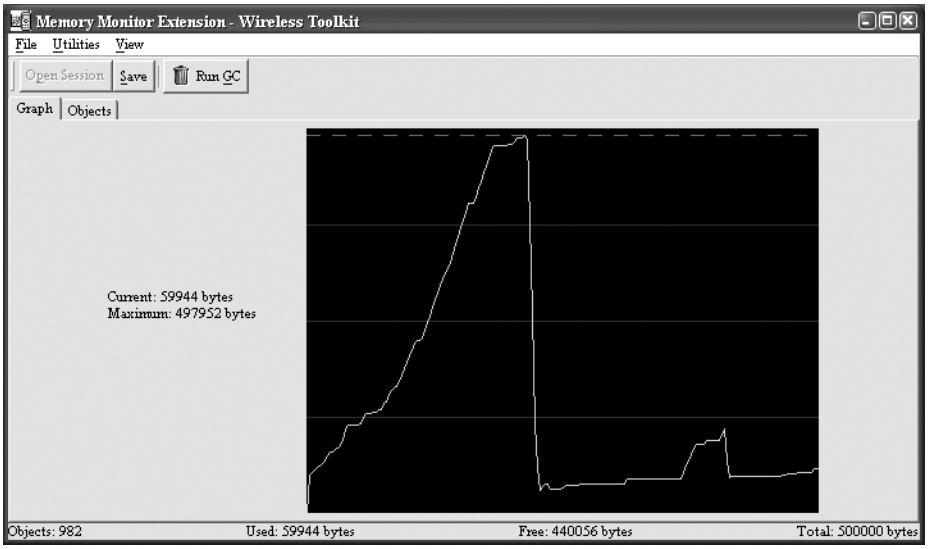


Figure 17-1. *Graph of memory use over time*

If you click the Objects tab in the memory monitor window, you'll see a detailed listing of the objects in your application. Figure 17-2 shows this view.

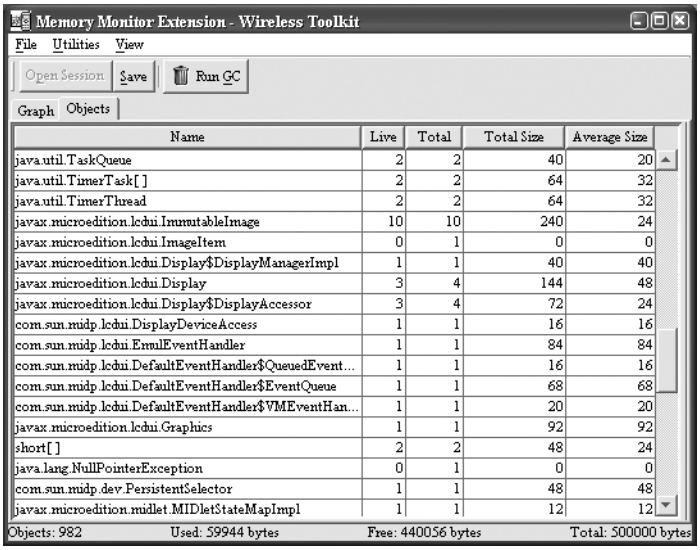


Figure 17-2. *Objects and their memory*

You won't see the profiler until you exit the emulator. When you do, the profiler window pops up, summarizing time spent in every method in your application during the last emulator run. Note that what you do in the emulator will affect the output in the profiler; if you want to test the performance of your application as a whole, you'll have to exercise all of its options. Figure 17-3 shows the emulator after running the `QuatschMIDlet` example from Chapter 11.

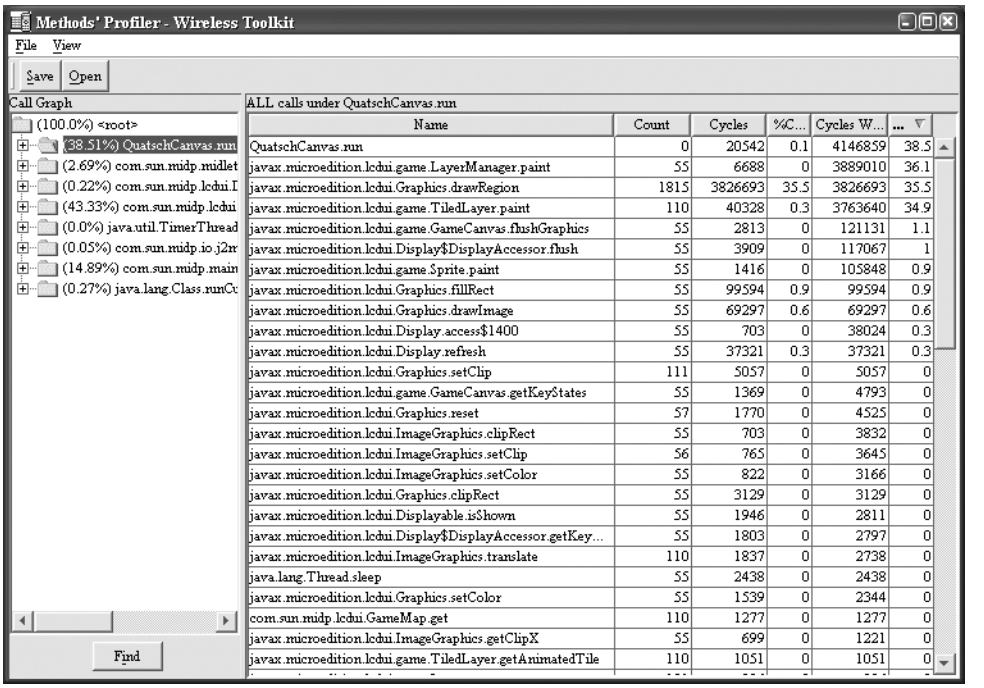

Methods' Profiler - Wireless Toolkit
File View
Save Open
Call Graph
(100.0%) <root>
(38.51%) QuatschCanvas.run
(2.69%) com.sun.midp.midlet
(0.22%) com.sun.midp.lcdui.I
(43.33%) com.sun.midp.lcdui
(0.0%) java.util.TimerThread
(0.05%) com.sun.midp.io.j2m
(14.89%) com.sun.midp.main
(0.27%) java.lang.Class.runCu
Find
ALL calls under QuatschCanvas.run
Name Count Cycles %C... Cycles W... ...
QuatschCanvas.run 0 20542 0.1 4146859 38.5
javax.microedition.lcdui.game.LayerManager.paint 55 6688 0 3889010 36.1
javax.microedition.lcdui.Graphics.drawRegion 1815 3826693 35.5 3826693 35.5
javax.microedition.lcdui.game.TiledLayer.paint 110 40328 0.3 3763640 34.9
javax.microedition.lcdui.game.GameCanvas.flushGraphics 55 2813 0 121131 1.1
javax.microedition.lcdui.Display$DisplayAccessor.flush 55 3909 0 117067 1
javax.microedition.lcdui.game.Sprite.paint 55 1416 0 105848 0.9
javax.microedition.lcdui.Graphics.fillRect 55 99594 0.9 99594 0.9
javax.microedition.lcdui.Graphics.drawImage 55 69297 0.6 69297 0.6
javax.microedition.lcdui.Display.access$1400 55 703 0 38024 0.3
javax.microedition.lcdui.Display.refresh 55 37321 0.3 37321 0.3
javax.microedition.lcdui.Graphics.setClip 111 5057 0 5057 0
javax.microedition.lcdui.game.GameCanvas.getKeyStates 55 1369 0 4793 0
javax.microedition.lcdui.Graphics.reset 57 1770 0 4525 0
javax.microedition.lcdui.ImageGraphics.clipRect 55 703 0 3832 0
javax.microedition.lcdui.ImageGraphics.setClip 56 765 0 3645 0
javax.microedition.lcdui.ImageGraphics.setColor 55 822 0 3166 0
javax.microedition.lcdui.Graphics.clipRect 55 3129 0 3129 0
javax.microedition.lcdui.Displayable.isShown 55 1946 0 2811 0
javax.microedition.lcdui.Display$DisplayAccessor.getKey... 55 1803 0 2797 0
javax.microedition.lcdui.ImageGraphics.translate 110 1837 0 2738 0
java.lang.Thread.sleep 55 2438 0 2438 0
javax.microedition.lcdui.Graphics.setColor 55 1539 0 2344 0
com.sun.midp.lcdui.GameMap.get 110 1277 0 1277 0
javax.microedition.lcdui.ImageGraphics.getClipX 55 699 0 1221 0
javax.microedition.lcdui.game.TiledLayer.getAnimatedTile 110 1051 0 1051 0

Figure 17-3. *The profiler times everything.*

Finally, the J2ME Wireless Toolkit also includes a network monitor. Although it's probably more useful for debugging network protocols than for optimization, it deserves mention here. To turn on the network monitor, choose Edit ➤ Preferences from the KToolbar menu. Choose the Monitoring tab and check off Enable Network Monitoring. Next time you run the emulator, a new window will pop up that tracks network usage. Figure 17-4 shows a few network interactions from the PeekAndPick application (`http://developers.sun.com/techtopics/mobility/applications/peekandpick/2.0/index.html`).

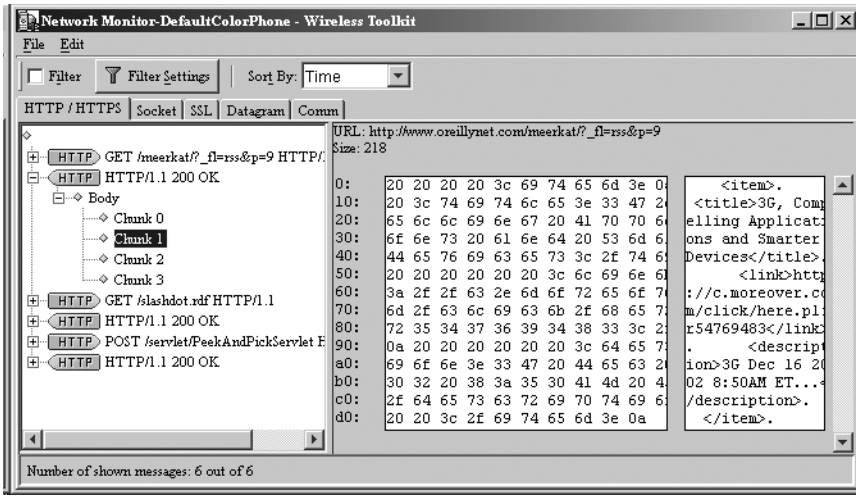


Figure 17-4. *Network activity from the PeekAndPick application*

Optimizing Memory Use

It's easy for J2SE programmers to be blasé about memory usage. After all, having a garbage collector means that you don't have to worry about explicitly freeing memory—objects that are no longer in use will be magically harvested by the garbage collector, running in a low-priority thread. In the J2ME universe, however, memory is scarce and should be treated with respect. Furthermore, both the allocation of memory and the work of the garbage collector can drag down the speed of your application. In this section, we'll look at techniques for efficient object use, particularly with `String`s and `StringBuffer`s. Finally, we'll talk about gracefully handling the situation when there really isn't any memory left.

Creating and Discarding Objects

If you're creating a new object inside a loop, it should be setting off alarm bells in your head. Every time you create an object (using `new`), memory is allocated. Allocating memory takes time. Worse, objects created at the beginning of a loop are likely to fall out of scope by the end of the loop, which means that each iteration through the loop pushes the runtime system closer to running the garbage collector. Here's an example:

```
// Set up the inputs and results arrays.
Object[] inputs = new Object[1000];
int[] results = new int[1000];
// Process each input to calculate a result.
int length = inputs.length;
for (int i = 0; i < length; i++) {
  Processor p = new Processor(inputs[i]);
  results[i] = p.calculateResult();
}
```

Creating objects in a loop imposes a double penalty in terms of performance. A new `Processor` is created every time through the loop; if these objects are large enough, then garbage collection may be forced one or more times before the loop is finished. You pay a price up front when the object is first created, then later when the object is garbage collected.

You can almost always restructure your code to avoid this problem. For example, instead of creating a new `Processor` for each input, you could do something like this:

```
// Set up the inputs and results arrays.
Object[] inputs = new Object[1000];
int[] results = new int[1000];
// Process each input to calculate a result.
int length = inputs.length;
Processor p = new Processor();
for (int i = 0; i < length; i++) {
  p.setInput(inputs[i]);
  results[i] = p.calculateResult();
}
```

Strings and StringBuffers

`Strings` have a special status in Java. They are the only objects for which the plus operator (+) is overloaded. Each time you concatenate strings using the plus operator, be wary—behind the scenes, new `String` and `StringBuffer` objects are being created for you.

`String` and `StringBuffer` share a curious relationship. When you can create and modify a `StringBuffer`, the actual work is performed on an internal character array. When you create a `String` from the `StringBuffer`, the `String` points to the same character array. Everything is fine so far, right? But if you further modify the `StringBuffer`, it cleverly creates a new character array, a copy of the old one. Thus, while `StringBuffer` is generally an efficient way to create `Strings`, it is not always obvious exactly when new objects are created.

The moral of the story is that every place you see string concatenation, there may be new objects being created. If you're assembling strings inside a loop, you should think about a different approach, possibly involving `StringBuffer`. Another possible optimization is to forego `String` and `StringBuffer` entirely and just use character arrays. While this may be a fast and efficient solution in your own code, keep in mind that many APIs require `Strings` as parameters and return `Strings` from methods, so you may end up doing a lot of conversion between character arrays and `Strings`.

Failing Gracefully

Given the paucity of memory in a typical MIDP device, your application should be prepared for disappointment each time it asks for memory. Each time objects are created, your code should catch `java.lang.OutOfMemoryError`. It is far better for you to catch `OutOfMemoryErrors` than for your host environment to catch them. You, at least, have a chance to do something reasonable—free up some memory and try again, or fail gracefully with a politely worded message to the user. The host environment is not likely to be so kind, and user perception of your application will be much worse. Bear in mind that you will probably need to free up memory by discarding large data structures before you will have enough space to create an `Alert` for your message to the user.

■ **Tip** One possible strategy in production programming is an attempt to allocate all memory up front, when the application first starts.

Coding for Speed

Small devices have small, relatively slow processors. Part of your task as a developer is ensuring your application runs fast enough that users won't reject it.

Optimize Loops

One simple optimization has to do with looping. A typical loop through a `Vector v` might look like this:

```
for (int i = 0; i < v.size(); i++) {
  Object o = v.elementAt(i);
  // Process the Object o.
}
```

Each time through the loop, v's `size()` method is called. An optimized version would store the size of the vector first, like this:

```
int size = v.size();
for (int i = 0; i < size; i++) {
  Object o = v.elementAt(i);
  // Process the Object o.
}
```

This is a simple example, but it illustrates that loop conditions are one place you can look for speed optimizations.

Use Arrays Instead of Objects

Arrays are usually faster and leaner than collection classes. We touched on this theme earlier in our discussion of `Strings` and `StringBuffers`; if it's not too clumsy, using character arrays directly will probably be more efficient than dealing with `String` and `StringBuffer` objects. The same rule applies to the MIDP collection classes `Vector` and `Hashtable`. Although `Vector` and `Hashtable` are simple and convenient, they do impose some overhead that can be trimmed. `Vector` is basically just a wrapper for an array, so if you can work with an array directly, you'll save yourself some memory and processing time. Similarly, if you have a simple mapping of key objects to value objects, it might make sense to use object arrays instead of `Hashtable`.

If you do decide to use `Hashtable` or `Vector`, try to size them correctly when you create them. Both `Vector` and `Hashtable` grow larger as needed, but it is relatively expensive. `Vector` creates a new internal array and copies elements from the old array to the new array. `Hashtable` allocates new arrays and performs a computationally expensive operation called *rehashing*. Both `Vector` and `Hashtable` have constructors that allow you to specify the initial size of the collection. You should specify the initial size of these collections as accurately as possible.

If you are using the persistent storage APIs, you may be tempted to wrap stream classes around the record data. For example, you might read a record, then wrap a `ByteArrayInputStream` around the record's data, and then wrap a `DataInputStream` around the `ByteArrayInputStream` to read primitive types from the record. This is likely too heavy to be practical. If at all possible, work directly with the record's byte array.

Use Buffered I/O

Don't read bytes one at a time from a stream, and don't write them out one at a time. Although the stream classes provide methods that read and write a single byte, you should avoid them if at all possible. It will almost always be more efficient to read or write a whole array full of data. File and network access is usually quite slow.

J2SE includes `BufferedReader` and `BufferedWriter` classes that provide buffering functionality "for free." There is no such luxury in the MIDP universe, so if you want to use buffering, you'll have to do it yourself.

Be Clean

One simple piece of advice is to clean up after yourself. Releasing resources as soon as you are done with them can improve the performance of your application. If you have internal arrays or data structures, you should free them when you're not using them. One way to do this is to set your array reference to `null` so that the array can be garbage collected. You could even call the garbage collector explicitly with `System.gc()` if you're anxious to release memory back to the runtime system.

■ **Caution** On most MIDP devices, continually acquiring and releasing resources can also degrade performance. This trade-off must be evaluated carefully.

Network connections should also be released as soon as you're done with them. One good way to do this is to use a `finally` clause. Consider the following code, which does not use a `finally` clause:

```
HttpConnection hc = null;
InputStream in = null;
try {
  hc = (HttpConnection)Connector.open(url);
  in = hc.openInputStream();
  // Read data from in.
  in.close();
  hc.close();
}
catch (IOException ioe) {
  // Handle the exception.
}
```

The problem occurs if an exception is thrown while you're trying to read data from the connection's input stream. In this case, execution jumps down to the exception handler, and the input stream and connection are never closed. In a J2SE environment, with memory to burn, this is probably not a big deal. But on a MIDP device, a hanging connection could be a disaster. When you absolutely, positively want to be sure to run some code, you should put it in a `finally` block like this:

```
HttpConnection hc = null;
InputStream in = null;
try {
  hc = (HttpConnection)Connector.open(url);
  in = hc.openInputStream();
  // Read data from in.
}
catch (IOException ioe) {
  // Handle the exception.
}
finally {
  try {
    if (in != null) in.close();
    if (hc != null) hc.close();
  }
  catch (IOException ioe) { }
}
```

This is starting to look a little ugly, particularly the `try` and `catch` inside our `finally` block. A cleaner solution would be to enclose this code in a method and declare that the method throws `IOException`. This cleans up the code considerably:

```
private void doNetworkStuff(String url) throws IOException {
  HttpConnection hc = null;
  InputStream in = null;
  try {
    hc = (HttpConnection)Connector.open(url);
    in = hc.openInputStream();
    // Read data from in.
  }
  finally {
    if (in != null) in.close();
    if (hc != null) hc.close();
  }
}
```

The deal with `finally` is that its code gets executed no matter how control leaves the `try` block. If an exception is thrown, or if somebody calls `return`, or even if control leaves the `try` block normally, our `finally` block still gets executed. Note that there is still a small amount of room for trouble here: if an exception is thrown when we try to close `in`, then `hc` will never be closed. You could enclose each `close()` call in its own `try` and `catch` block to handle this problem.

Being clean applies to any type of stream, record stores, and record enumerations. Anything that can be closed should be, preferably in a `finally` block.

Optimize the User Interface

It's important to remember that you are trying to optimize the *perceived* speed of your application, not the actual speed of the application. Users get fidgety if the application freezes up for a few seconds; adding some sort of progress indicator can go a long way toward making users happier. There's really nothing you can do to make the network run faster, but if you display a spinning clock or a moving progress bar, your application will at least look like it's still alive while it's waiting for the network.

Keep in mind that users of mobile phones and other small "consumer" devices will be much more demanding than typical desktop computer users. Through years of experience, bitter desktop computer users have fairly low expectations of their applications. They realize that most desktop applications have a learning curve and are frequently cantankerous. Consumer devices, on the other hand, are much more likely to work right the first time, requiring neither manuals nor advanced degrees to operate.

With this in mind, be sure that your MIDlet user interface is uncomplicated, fast, responsive, intuitive, and informative.

Optimizing Application Deployment

One last area of optimization has to do with the actual deployment of your application. As you may remember from Chapter 3, MIDlets are packaged in MIDlet suites, which are really just fancy JAR files. One way to optimize your application is to partition your classes so that only the ones you need are loaded into the runtime environment. If you are careful, you can reduce the size of your MIDlet suite JAR by eliminating classes you don't need. Finally, a code obfuscator may be used to further reduce the size of the MIDlet suite JAR.

■ **Tip** In general, you should be careful not to use an excessive number of classes in your application. Each class you use has a fixed memory/storage overhead.

Partition Your Application

The MIDP runtime environment loads classes as they are needed. You can use this to your advantage to optimize the runtime footprint of your application. For example, suppose you write a datebook application that has the capability to send you reminder e-mails, or *ticklers*. You would probably realize that many people will not take advantage of the tickler feature. Why should tickler code take up space in a MIDP device if the user is not using ticklers? If you partition your code correctly, all of the tickler functionality can be encapsulated in a single class. If the rest of the application never calls the tickler code, the class will not be loaded, resulting in a slimmer runtime footprint.

Only Include Classes You Need

You may be using third-party packages in your MIDlet suite, like a cryptography package (see Chapter 18). For development, you might have simply dumped the whole package into your MIDlet suite. But come deployment time, you should prune out the excess packages to reduce the size of your MIDlet suite JAR. In some cases this will be fairly easy, like dumping out `OBEX` classes if you're only using the Bluetooth support. Other times it will not be so obvious which classes you need and which ones you can get rid of. However, if you really want to reduce your MIDlet suite JAR size, this is a crucial step. You don't need to do this by hand; an *obfuscator* will do the work for you.

Use an Obfuscator

Finally, a *bytecode obfuscator* can reduce the size of your class files. A bytecode obfuscator is a tool that is supposed to make it difficult to decompile class files. Decompilation is a process by which someone can re-create the source code that was used to make a particular class file. People who are worried about competitors stealing their code use obfuscators to make decompilation more difficult. However, obfuscation has the side effect of reducing class file size, mainly because the descriptive method and variable names you created are replaced with small machine-generated names. Some obfuscators will also remove unused code. If you're very serious about reducing the size of your MIDlet suite JAR, try obfuscating your code. We suggest running the obfuscator before preverifying the class files, but it's conceivable it would work the other way around, too. Here are two obfuscators to get you started:

```
http://proguard.sourceforge.net/
http://www.retrologic.com/retroguard-main.html
```

Summary

MIDP applications are targeted to run on a small platform, which means that using memory and processing power efficiently is important. Creating and destroying objects is expensive, so one way to optimize your code is to reduce the number of objects you create. One common source of new objects is code that creates `String`s. Consider optimizing `String` manipulation using `StringBuffer` or character arrays. Similarly, you may be able to streamline code by using object arrays in place of `Vector`s or `Hashtable`s. Remember that performance is as much about perception as anything else; provide a responsive, active user interface and handle failures gracefully. You can also optimize the delivery of your application in several ways. First, partitioning the functionality of your application intelligently can reduce the runtime footprint of your application. Next, trimming out excess classes can reduce the size of your MIDlet suite JAR. Finally, a bytecode obfuscator can further reduce the size of your MIDlet suite JAR.

CHAPTER 18

Protecting Network Data

MIDlets are undeniably cool—providing Java code that runs on a small device and HTTP network connectivity as well. But once you start thinking about the possibilities, you realize that a lot of applications just aren't possible without some form of data security. What if you were going to buy something? You shouldn't send credit card numbers over the Internet without some kind of protection, and you shouldn't send sensitive corporate information over the Internet to small devices. Many applications, then, need something else—something that keeps sensitive data from being stolen. The answer in the MIDP world is no different than the answer anywhere else: cryptography.

Cryptography Review

Cryptography is a branch of mathematics. It's based on the idea that certain kinds of mathematical problems are hard to solve. Using cryptography is a bit speculative; as research in mathematics continues, it's very possible that someone will discover a way to solve (or "break") most of the modern cryptographic algorithms. Nevertheless, for today at least, cryptography provides protection for sensitive data, and there aren't many acceptable alternatives in the everything-connects-to-everything modern world.

The Internet Is a Big Room

There are many aspects to the security of a system. We'll focus on the data your MIDlet sends and receives over the network. This data travels over some infrastructure most know nothing about (provided by your mobile carrier) and probably over the Internet, as well. The Internet is definitely not a secure network, and your carrier's mobile infrastructure probably isn't either. If you're passing sensitive data around, it's very possible that eavesdroppers at various points in the network can listen in on the data. They may even be able to change parts of it. If your MIDP application involves passing around credit card numbers or sensitive corporate data, you should be concerned.

Think of the Internet as a big room. You can talk to anyone else in the room, but everyone else can listen in on the conversation. Furthermore, you may be talking to someone on the other side of the room through intermediaries, like the children's game of "telephone." Any one of the intermediaries might be changing the conversation, and they can all hear what you're saying.

Data Security Needs and Cryptographic Solutions

Your applications will have some or all of the following data security needs:

- *Integrity*: At the simplest level, you'd like to be sure that the data you're sending is not getting changed or corrupted in any way. This is data integrity.
- *Authentication*: It's often important to verify the identity of the machine or person on the other end of your network connection. Authentication is the process of proving identity.
- *Confidentiality*: If you're sending sensitive data over the network, other people shouldn't be able to see that information. This is confidentiality.

Cryptography provides solutions for each of these needs:

- *Message digests*: A message digest smushes a large piece of data into a small piece of data. You might, for example, run an entire file through a message digest to end up with a 160-bit digest value. If you change even 1 bit of the file and run it through the message digest again, you'll get an entirely different digest value. A message digest value is sometimes called a *digital fingerprint*.
- *Digital signatures*: A digital signature is like a message digest except it is produced by a particular person, the *signer*. The signer must have a *private key* that is used to create the signature. A corresponding *public key* can be used by anyone to verify that the signature came from the signer. The private key and public key together are called a *key pair*. Keys are really just data—think of an array of bytes. *Certificates* are really just an extension of digital signatures. A certificate is a document, signed by some authority like the U.S. Postal Service, that proves your identity. It's like a driver's license, except it's based on digital signatures.
- *Ciphers*: Ciphers can either encrypt data or decrypt it. An encrypting cipher accepts your data, called *plaintext*, and produces an unreadable mess, called *ciphertext*. A decrypting cipher takes ciphertext and converts it back to plaintext. Ciphers use keys; if you encrypt the same plaintext with two different keys, you'll get two different sets of ciphertext. A *symmetric* cipher uses the same key for encryption and decryption. An *asymmetric* cipher operates with a key pair—one key is used for encrypting, while the matching key is used for decrypting. Ciphers operate in different *modes* that determine how plaintext is encrypted into ciphertext. This, in turn, affects the use and security of the cipher.

■ **Note** For comprehensive coverage of cryptographic concepts and algorithms, see Bruce Schneier's *Applied Cryptography: Protocols, Algorithms, and Source Code in C* (John Wiley & Sons, 1995). To find out more about the JCA and JCE in J2SE, read Jonathan's *Java Cryptography* (O'Reilly, 1998). Sun's developer web site also contains Jonathan's excellent four-part series on security and cryptography in MIDP, located at `http://developers.sun.com/techtopics/mobility/midp/articles/security1/`.

HTTPS Is Almost Everything You Could Want

The Generic Connection Framework has always been flexible enough to allow MIDP implementations to include support for HTTPS, which is HTTP over a secure connection like TLS or SSL. Support for HTTPS is built into the MIDP platform. (See Chapter 10 for the skinny on HTTPS and its supporting APIs.)

TLS provides server authentication and an encrypted data connection between client and server. The security provided by TLS is sufficient for most applications. There are only a handful of reasons you might want to implement cryptographic solutions beyond what's available from TLS, including the following:

- *Client authentication*: TLS provides server authentication, usually via an RSA certificate. But although TLS will support client authentication, the APIs in MIDP 2.0 don't allow you to take advantage of this feature. A technique for using password or passphrase authentication is presented later in this chapter (see the section "Protecting Passwords with a Message Digest"). If you're looking for something stronger, a scheme based on client certificates and signatures is described at `http://developers.sun.com/techtopics/mobility/midp/articles/security3/`.

- *Stronger encryption*: TLS usually results in encryption using 128-bit keys that are valid for a particular session. (Although you can't control which cipher suites are accepted on the client, you will probably have control of the server and will be able to configure acceptable cipher suites there.) For many applications, 128-bit session keys provide plenty of data security. However, if your application deals with especially sensitive or valuable data, you might want something stronger.

- *Message-driven applications*: HTTPS only provides encryption for channels. Some applications work by sending encrypted messages over insecure transport like HTTP or sockets. Here the MIDP APIs are insufficient and you'll need to do your own cryptography.

As we said, HTTPS support in MIDP is all you need for many applications. Read on if you need something stronger, or if you're just curious.

More information about HTTPS and TLS in MIDP is at `http://wireless.java.sun.com/midp/articles/security2/`.

The Bouncy Castle Cryptography Package

In the J2SE world, Sun provides support for cryptography through the Java Cryptography Architecture (JCA) and the Java Cryptography Extension (JCE). The problem, of course, is that the JCA and JCE are too heavy for the MIDP platform. MIDP's HTTPS support is very useful, but it's definitely not a general-purpose cryptography toolkit.

If you're looking to move beyond HTTPS, your best bet is the Bouncy Castle cryptography package, an open-source effort based in Australia. It's a wonderful piece of work, featuring a clean API and a formidable toolbox of cryptographic algorithms. There are several other open source cryptography packages around the world, but Bouncy Castle specifically offers a lightweight J2ME distribution of their software. To download the package, go to `http://www.bouncycastle.org/`, follow the link for latest releases, and choose the J2ME release of the lightweight API. As we write this, the current version is 1.27.

Download the zip file into the location of your choice and unpack it. If you're using the J2ME Wireless Toolkit, just drop the `midp_classes.zip` file (extracted from your Bouncy Castle lightweight API for J2ME download) into the `lib` directory of your project. You can go ahead and write MIDlets that use the Bouncy Castle packages.

Protecting Passwords with a Message Digest

Having installed the Bouncy Castle cryptography package, try a simple example involving authentication. Computer systems often use passwords instead of digital signatures (or certificates) because they're so much easier. A password is a *shared secret*, which means that you know it and the server knows it, but nobody else should know it.

WHAT IF SOMEONE STEALS YOUR PHONE?

For convenience, an application will probably store your password in persistent storage. This is a conscious trade-off of security for usability. The user never enters a password, but the password is available in device storage, vulnerable to theft by other applications on the device. Furthermore, if someone steals the device itself, that person will be able to use the application without being challenged for a password.

JSR 177, Security and Trust Services for J2ME (`http://jcp.org/en/jsr/detail?id=177`), will address these concerns by providing an API to secure storage, among other things.

The Problem with Passwords

The problem with passwords is that you don't want to send them over an insecure network. Imagine, for example, that your MIDlet requires the user to sign on to a server using a user name and password. On the MIDP device, you key in your user name and password, and then click the button to send the information up to the server. Unfortunately, your data is sent as plaintext in some HTTP request. Anybody snooping on the network can easily lift your password.

Using a Message Digest

Message digests provide a way to solve this problem. Instead of sending a password as plaintext, you create a message digest value from the password and send that instead. An attacker could just steal the digest value, of course, so you add some other stuff to the digest as well so that only the server, knowing the password, can re-create the same digest value. Figure 18-1 shows the process.

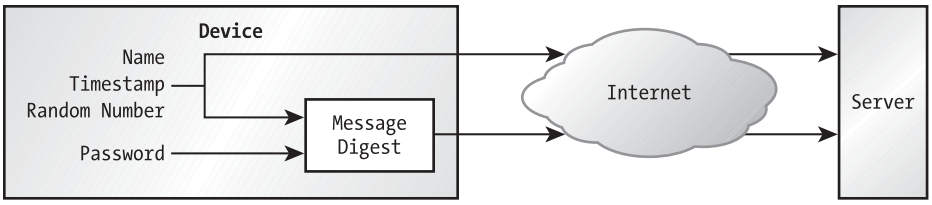


Figure 18-1. *Protecting a password with a message digest*

The MIDlet creates a timestamp and a random number, both of which are fed into the message digest along with the user name and the password. Then the MIDlet sends the user name, the timestamp, the random number, and the digest value up to the server. It does not send the password as cleartext, but the password is used to calculate the digest value.

The server takes the user name and looks up the corresponding password, which should be stored securely in a file or a database. Then it creates a digest value of the user name, password, timestamp, and random number. If the digest value created on the server matches the digest value sent by the client MIDlet, then the server knows that the user typed in the right password. The user has just logged in successfully.

The server needs some logic to prevent replay attacks. Specifically, the server should reject login attempts that use timestamps and random numbers that have been used before with that login. Although you could save the random numbers and timestamps of all user login attempts, it would be relatively expensive to compare each of these every time a user wanted to log in. An easier way to implement this is to save the timestamp of each user's last login attempt. For each subsequent login attempt, the server looks up the saved timestamp. If the timestamp on the current attempt is later than the saved timestamp, the attempt is allowed. The current attempt's timestamp replaces the saved timestamp for this user.

Using the Bouncy Castle Cryptography Package

In the Bouncy Castle package, message digests are generically represented by the `org.bouncycastle.crypto.Digest` interface. You can add data into the message digest using one of two `update()` methods. To calculate the message digest value, call `doFinal()`. Specific implementations of the `Digest` interface are contained in the `org.bouncycastle.crypto.digests` package. We'll be using one called `SHA1Digest`, which implements the SHA-1 digest algorithm. The following line shows how to create a SHA-1 message digest object:

```
Digest digest = new SHA1Digest();
```

The cryptography code is pretty simple. Most of the effort, in fact, is devoted to converting the timestamp and random number to bytes that can be pushed into the message digest object. Then it's just a matter of calling the `update()` method with each array of bytes.

To calculate the digest, call `Digest`'s `doFinal()` method. You'll need to pass in a byte array to hold the message digest value. To find out how long this array should be, call the `getDigestSize()` method.

```
byte[] digestValue = new byte[digest.getDigestSize()];
digest.dofinal(digestValue, 0);
```

Implementing a Protected Password Protocol

This section details an implementation of protected password login. On the client side, a MIDlet collects a user name and password, as shown in Figure 18-2.

When the `Login` command is invoked, the MIDlet sends data to a servlet, which determines whether or not the client is authenticated. The servlet sends back a message, which is displayed on the screen of the device, as shown in Figure 18-3.

Figure 18-2. *A simple form collects a user name and password.*

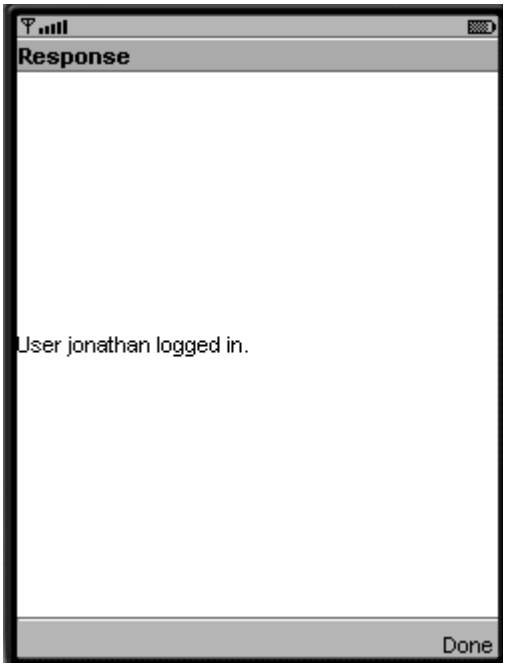


Figure 18-3. *The server says whether you're logged in or not.*

The MIDlet and servlet exchange various byte arrays, such as the timestamp, the random number, and the message digest value. To make this work smoothly in the context of HTTP headers, which are plain text, the byte arrays are exchanged as hexadecimal strings. A helper class, `HexCodec`, handles the translation between hexadecimal strings and byte arrays. This same class is used by the MIDlet and the servlet.

Let's look at the MIDlet first. Its main screen is a form in which the user can enter a user name and a password. You might be tempted to use a `PASSWORD TextField`, but we chose not to. For one thing, it's hard to know exactly what text you're entering. For another thing, we're assuming that the screen of a small device is reasonably private—probably no one will be peeking over your shoulder as you enter your password.

When the user invokes the `Login` command, the MIDlet calculates a message digest value as described previously. It assembles various parameters into an HTTP request. It then reads the response from the server and displays the response in an `Alert`.

The meat of the protected password algorithm is in the `login()` method. We create a timestamp and a random number and convert these values to byte arrays using a helper method:

```
long timestamp = System.currentTimeMillis();
long randomNumber = mRandom.nextLong();
byte[] timestampBytes = getBytes(timestamp);
byte[] randomBytes = getBytes(randomNumber);
```

The user name and password strings, which come from the MIDlet's main form, are easily converted to byte arrays.

The entire source code for `PasswordMIDlet` is shown in Listing 18-1.

Listing 18-1. *PasswordMIDlet, a Protected Password Client*

```
import java.io.*;
import java.util.Random;

import javax.microedition.io.*;
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

import org.bouncycastle.crypto.Digest;
import org.bouncycastle.crypto.digests.SHA1Digest;

public class PasswordMIDlet
    extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;
  private Form mForm;
  private TextField mUserField, mPasswordField;
  private Random mRandom;

  public void startApp() {
    mDisplay = Display.getDisplay(this);
    mRandom = new Random(System.currentTimeMillis());
```

```
    if (mForm == null) {
      mForm = new Form("Login");
      mUserField = new TextField("Name", "jonathan", 32, 0);
      mPasswordField = new TextField("Password", "happy8", 32, 0);
      mForm.append(mUserField);
      mForm.append(mPasswordField);

      mForm.addCommand(new Command("Exit", Command.EXIT, 0));
      mForm.addCommand(new Command("Login", Command.SCREEN, 0));
      mForm.setCommandListener(this);
    }

    mDisplay.setCurrent(mForm);
  }

  public void commandAction(Command c, Displayable s) {
    if (c.getCommandType() == Command.EXIT) notifyDestroyed();
    else {
      Form waitForm = new Form("Connecting...");
      mDisplay.setCurrent(waitForm);
      Thread t = new Thread(this);
      t.start();
    }
  }

  public void run() {
    // Gather the values we'll need.
    long timestamp = System.currentTimeMillis();
    long randomNumber = mRandom.nextLong();
    String user = mUserField.getString();
    byte[] userBytes = user.getBytes();
    byte[] timestampBytes = getBytes(timestamp);
    byte[] randomBytes = getBytes(randomNumber);
    String password = mPasswordField.getString();
    byte[] passwordBytes = password.getBytes();

    // Create the message digest.
    Digest digest = new SHA1Digest();
    // Calculate the digest value.
    digest.update(userBytes, 0, userBytes.length);
    digest.update(timestampBytes, 0, timestampBytes.length);
    digest.update(randomBytes, 0, randomBytes.length);
    digest.update(passwordBytes, 0, passwordBytes.length);
    byte[] digestValue = new byte[digest.getDigestSize()];
    digest.doFinal(digestValue, 0);
```

```
    // Create the GET URL. The hex encoded message digest value is
    //   included as a parameter.
    URLBuilder ub = new URLBuilder(getAppProperty("PasswordMIDlet-URL"));
    ub.addParameter("user", user);
    ub.addParameter("timestamp",
        new String(HexCodec.bytesToHex(timestampBytes)));
    ub.addParameter("random",
        new String(HexCodec.bytesToHex(randomBytes)));
    ub.addParameter("digest",
        new String(HexCodec.bytesToHex(digestValue)));
    String url = ub.toString();

    try {
      // Query the server and retrieve the response.
      HttpConnection hc = (HttpConnection)Connector.open(url);
      InputStream in = hc.openInputStream();

      int length = (int)hc.getLength();
      byte[] raw = new byte[length];
      in.read(raw);
      String response = new String(raw);
      Alert a = new Alert("Response", response, null, null);
      a.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(a, mForm);
      in.close();
      hc.close();
    }
    catch (IOException ioe) {
      Alert a = new Alert("Exception", ioe.toString(), null, null);
      a.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(a, mForm);
    }
  }

  private byte[] getBytes(long x) {
    byte[] bytes = new byte[8];
    for (int i = 0; i < 8; i++)
      bytes[i] = (byte)(x >> ((7 - i) * 8));
    return bytes;
  }

  public void pauseApp() { }

  public void destroyApp(boolean unconditional) { }
}
```

The HexCodec class contains a few static methods for converting between byte arrays and hex encoded strings. The complete class is shown in Listing 18-2.

Listing 18-2. *The HexCodec Helper Class*

```
public class HexCodec {
  private static final char[] kDigits = {
    '0', '1', '2', '3', '4', '5', '6', '7', '8', '9',
    'a', 'b', 'c', 'd', 'e', 'f'
  } ;

  public static char[] bytesToHex(byte[] raw) {
    int length = raw.length;
    char[] hex = new char[length * 2];
    for (int i = 0; i < length; i++) {
      int value = (raw[i] + 256) % 256;
      int highIndex = value >> 4;
      int lowIndex = value & 0x0f;
      hex[i * 2 + 0] = kDigits[highIndex];
      hex[i * 2 + 1] = kDigits[lowIndex];
    }
    return hex;
  }

  public static byte[] hexToBytes(char[] hex) {
    int length = hex.length / 2;
    byte[] raw = new byte[length];
    for (int i = 0; i < length; i++) {
      int high = Character.digit(hex[i * 2], 16);
      int low = Character.digit(hex[i * 2 + 1], 16);
      int value = (high << 4) | low;
      if (value > 127) value -= 256;
      raw[i] = (byte)value;
    }
    return raw;
  }

  public static byte[] hexToBytes(String hex) {
    return hexToBytes(hex.toCharArray());
  }
}
```

PasswordMIDlet also uses the URLBuilder class, which provides a simple interface for assembling GET URLs. The URLBuilder class is shown in Listing 18-3.

Listing 18-3. *The URLBuilder Helper Class*

```
public class URLBuilder {
  private StringBuffer mBuffer;
  private boolean mHasParameters;

  public URLBuilder(String base) {
    mBuffer = new StringBuffer(base);
    mHasParameters = false;
  }

  public void addParameter(String name, String value) {
    // Append a separator.
    if (mHasParameters == false) {
      mBuffer.append('?');
      mHasParameters = true;
    }
    else
      mBuffer.append('&');
    // Now tack on the name and value pair. These should
    //   really be URL encoded (see java.net.URLEncoder in
    //   J2SE) but this class appends the name and value
    //   as is, for simplicity. Names or values with spaces
    //   or other special characters will not work correctly.
    mBuffer.append(name);
    mBuffer.append('=');
    mBuffer.append(value);
  }

  public String toString() {
    return mBuffer.toString();

  }
}
```

You will need to set the MIDlet property `PasswordMIDlet-URL` to point to the location of the running `PasswordServlet`.

A simple implementation of a protected password servlet is shown in Listing 18-4.

Listing 18-4. *The PasswordServlet Class*

```
import javax.servlet.http.*;
import javax.servlet.*;
import java.io.*;
import java.util.*;
```

```
import org.bouncycastle.crypto.Digest;
import org.bouncycastle.crypto.digests.SHA1Digest;

public class PasswordServlet extends HttpServlet {
  public void doGet(HttpServletRequest request,
      HttpServletResponse response)
      throws ServletException, IOException {
    System.out.println("user = " + request.getParameter("user"));
    System.out.println("timestamp = " + request.getParameter("timestamp"));
    System.out.println("random = " + request.getParameter("random"));
    System.out.println("digest = " + request.getParameter("digest"));

    // Retrieve the user name.
    String user = request.getParameter("user");
    // Look up the password for this user.
    String password = lookupPassword(user);
    // Pull the timestamp and random number (hex encoded) out
    //   of the request.
    String timestamp = request.getParameter("timestamp");
    String randomNumber = request.getParameter("random");

    // Compare the timestamp with the last saved
    //   timestamp for this user. Accept only timestamps
    //   that are greater than the last saved timestamp for this user.
    // [not implemented]

    // Gather values for the message digest.
    byte[] userBytes = user.getBytes();
    byte[] timestampBytes = HexCodec.hexToBytes(timestamp);
    byte[] randomBytes = HexCodec.hexToBytes(randomNumber);
    byte[] passwordBytes = password.getBytes();
    // Create the message digest.
    Digest digest = new SHA1Digest();
    // Calculate the digest value.
    digest.update(userBytes, 0, userBytes.length);
    digest.update(timestampBytes, 0, timestampBytes.length);
    digest.update(randomBytes, 0, randomBytes.length);
    digest.update(passwordBytes, 0, passwordBytes.length);
    byte[] digestValue = new byte[digest.getDigestSize()];
    digest.doFinal(digestValue, 0);

    // Now compare the digest values.
    String message = "";
    String clientDigest = request.getParameter("digest");
    if (isEqual(digestValue, HexCodec.hexToBytes(clientDigest)))
      message = "User " + user + " logged in.";
    else
      message = "Login was unsuccessful.";
```

```
    // Send a response to the client.
    response.setContentType("text/plain");
    response.setContentLength(message.length());
    PrintWriter out = response.getWriter();
    out.println(message);
  }

  private String lookupPassword(String user) {
    // Here you could do a real lookup based on the user name.
    //   You might look in a text file or a database. Here, we
    //   just use a hard-coded value.
    return "happy8";
  }

  private boolean isEqual(byte[] one, byte[] two) {
    if (one.length != two.length) return false;
    for (int i = 0; i < one.length; i++)
      if (one[i] != two[i]) return false;
    return true;
  }
}
```

The basic procedure is to pull the parameters out of the request from the MIDlet, and then independently calculate the message digest value. The servlet looks up the user's password in the `lookupPassword()` method. In a more serious implementation, the servlet would probably look up the password in a database of some sort.

Once the servlet figures out the user's password, it pumps the user name, password, timestamp, and random number into a message digest. Then it calculates the message digest value and compares this result with the digest value that was sent from the MIDlet. If the digest values match, the MIDlet client is authenticated.

Suggested Enhancements

One obvious enhancement to this system is to actually retrieve passwords (on the server side) from a database or password repository of some sort.

Furthermore, the servlet needs to validate the timestamp it receives from the client. Every time a user tries to log in, the servlet should make sure that the user's timestamp is greater than the timestamp from the user's previous login attempt.

One possible enhancement on the client side is to store the user's name and password in a record store so that they can be automatically sent with each login attempt. Normally this might seem like a bad idea. But small devices are generally kept physically secure by their owners—you try to keep your mobile phone in your possession at all times, or you lock it up somewhere. It's a trade-off between convenience and security. But just considering how difficult it is to enter text on a mobile phone keypad, you might want to give your users the convenience of using a stored name and password.

Note that the authentication performed in this scheme is *per request*. Each time the client sends an HTTP request to the server, it is an entirely separate conversation. Therefore, each time the client needs to authenticate itself to the server to perform some work, it must go through the whole process again—creating a timestamp and random number, calculating a message digest, and sending the whole mess up to the server. In this system, then, you would probably add parameters to the HTTP request that specify an action or command that should be performed on behalf of the authenticated user.

Securing Network Data

Let's look at something a little more complicated. Suppose you wish to conceal the data you are sending over the network. The protected password example showed one way for a client to authenticate itself to the server, but we've still got the problem of eavesdroppers picking up credit card numbers or other sensitive information off the network.

This example consists of a matched MIDlet and servlet. The MIDlet, `StealthMIDlet`, has a simple user interface that allows you to enter a message. This message is encrypted using an RC4 stream cipher and sent to the servlet. On the server side, `StealthServlet` receives the encrypted message, decrypts it, and sends back its own encrypted message. Both messages pass over the insecure Internet as ciphertext, which is difficult for attackers to read without the proper keys.

RC4 is a symmetric encryption algorithm, which means that the same key is used to encrypt and decrypt data. `StealthMIDlet` and `StealthServlet` use two keys, one for each direction of data travel. One key is used to encrypt data in the MIDlet and decrypt it in the servlet; the other key encrypts data in the servlet and decrypts it in the MIDlet.

The servlet services multiple client MIDlets, each with their own encrypting and decrypting keys. Therefore, the servlet must keep track of two keys per client without getting them mixed up. It uses an HTTP session object to do this. Every time a client request is received, the servlet finds the corresponding ciphers in the session object. If the ciphers don't exist, they are created and initialized using client-specific keys.

This system provides both data confidentiality and authentication. The client and server are authenticated to each other because they must possess the correct keys to exchange data.

Figure 18-4 shows the main user interface of `StealthMIDlet`. It allows you to enter a message you want to encrypt and send to the server. When you're ready, hit the `Send` command to kick things off.

The servlet decrypts your message and sends back an encrypted response, which is displayed by the MIDlet as shown in Figure 18-5.

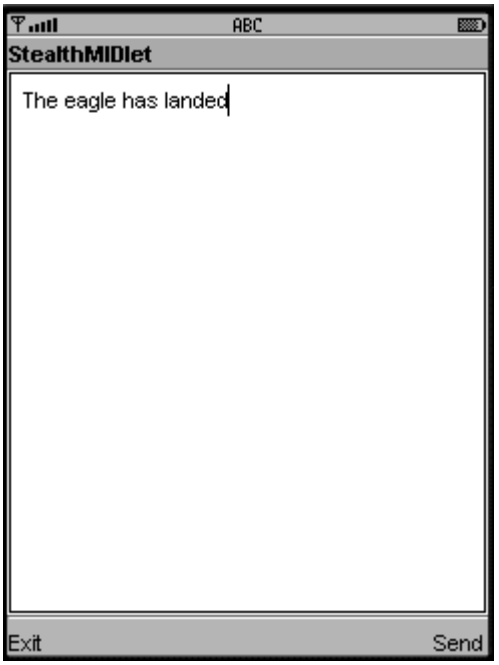


Figure 18-4. *Enter your secret message in StealthMIDlet's main screen.*

Figure 18-5. *The servlet sends back its own secret message.*

Using Bouncy Castle Ciphers

In the Bouncy Castle cryptography package, stream ciphers are represented by the `org.bouncycastle.crypto.StreamCipher` interface. You just need to initialize the cipher, using `init()`, and then you can encrypt or decrypt data using `processBytes()`.

The Bouncy Castle package only provides one direct stream cipher implementation, `org.bouncycastle.crypto.engines.RC4`. If you'd prefer to use a different algorithm, you can use a block cipher instead. You can treat block ciphers like stream ciphers using Cipher Feedback (CFB) mode. In the Bouncy Castle package, this is implemented in the `org.bouncycastle.crypto➥.StreamBlockCipher` class. This technique gives you access to Bouncy Castle's considerable arsenal of block cipher implementations, from the wizened DES through AES, Blowfish, Rijndael, and more. For more information on cipher modes, see Chapter 7 of *Java Cryptography*.

Our simple implementation instantiates a pair of `RC4` objects, something like this:

```
StreamCipher inCipher = new RC4Engine();
StreamCipher outCipher = new RC4Engine();
```

The ciphers need to be initialized before they can be used. The first parameter to `init()` should be `true` if the cipher will be encrypting data, `false` for decryption. The second parameter is essentially the key, wrapped up in a `KeyParameter` object.

```
// Assume we have retrieved inKey and outKey, both byte arrays.
inCipher.init(false, new KeyParameter(inKey));
outCipher.init(true, new KeyParameter(outKey));
```

To encrypt data, we just need to create an array to hold the ciphertext. Then call the stream cipher's `processBytes()` method to perform the encryption. The `processBytes()` method accepts the plaintext array, an index into the plaintext, the number of bytes that should be processed, the ciphertext array, and the index at which the ciphertext should be written.

```
// Assume we have a byte array called plaintext.
byte[] ciphertext = new byte[plaintext.length];
outCipher.processBytes(plaintext, 0, plaintext.length, ciphertext, 0);
```

Decryption is identical, except you would use a cipher that has been initialized for decryption.

Implementation

The source code for `StealthMIDlet` is shown in Listing 18-5. This MIDlet has a simple user interface, initialized in the `startApp()` method. The MIDlet's ciphers are also created and initialized in `startApp()`.

Listing 18-5. *StealthMIDlet, a Data Encryption MIDlet*

```
import java.io.*;

import javax.microedition.io.*;
import javax.microedition.midlet.*;
import javax.microedition.lcdui.*;

import org.bouncycastle.crypto.StreamCipher;
import org.bouncycastle.crypto.engines.RC4Engine;
import org.bouncycastle.crypto.params.KeyParameter;

public class StealthMIDlet
    extends MIDlet
    implements CommandListener, Runnable {
  private Display mDisplay;
  private TextBox mTextBox;

  private String mSession;
  private StreamCipher mOutCipher, mInCipher;

  public StealthMIDlet() {
    mOutCipher = new RC4Engine();
    mInCipher = new RC4Engine();
  }

  public void startApp() {
    if (mSession == null) {
      // Load the keys from resource files.
      byte[] inKey = getInKey();
      byte[] outKey = getOutKey();

      // Initialize the ciphers.
      mOutCipher.init(true, new KeyParameter(outKey));
      mInCipher.init(false, new KeyParameter(inKey));
    }

    mDisplay = Display.getDisplay(this);

    if (mTextBox == null) {
      mTextBox = new TextBox("StealthMIDlet",
          "The eagle has landed", 256, 0);
```

```
    mTextBox.addCommand(new Command("Exit", Command.EXIT, 0));
    mTextBox.addCommand(new Command("Send", Command.SCREEN, 0));
    mTextBox.setCommandListener(this);
  }

  mDisplay.setCurrent(mTextBox);
}

public void commandAction(Command c, Displayable s) {
  if (c.getCommandType() == Command.EXIT) notifyDestroyed();
  else {
    Form waitForm = new Form("Connecting...");
    mDisplay.setCurrent(waitForm);
    Thread t = new Thread(this);
    t.start();
  }
}

public void run() {
  // Encrypt our message.
  byte[] plaintext = mTextBox.getString().getBytes();
  byte[] ciphertext = new byte[plaintext.length];
  mOutCipher.processBytes(plaintext, 0, plaintext.length, ciphertext, 0);
  char[] hexCiphertext = HexCodec.bytesToHex(ciphertext);

  // Create the GET URL. Our user name and the encrypted, hex
  //   encoded message are included as parameters. The user name
  //   and base URL are retrieved as application properties.
  String baseURL = getAppProperty("StealthMIDlet-URL");
  URLBuilder ub = new URLBuilder(baseURL);
  ub.addParameter("user", getAppProperty("StealthMIDlet.user"));
  ub.addParameter("message", new String(hexCiphertext));
  String url = ub.toString();

  try {
    // Query the server and retrieve the response.
    HttpConnection hc = (HttpConnection)Connector.open(url);
    if (mSession != null)
      hc.setRequestProperty("cookie", mSession);
    InputStream in = hc.openInputStream();

    String cookie = hc.getHeaderField("Set-cookie");
    if (cookie != null) {
      int semicolon = cookie.indexOf(';');
      mSession = cookie.substring(0, semicolon);
    }
```

```
      int length = (int)hc.getLength();
      ciphertext = new byte[length];
      in.read(ciphertext);
      in.close();
      hc.close();
    }
    catch (IOException ioe) {
      Alert a = new Alert("Exception", ioe.toString(), null, null);
      a.setTimeout(Alert.FOREVER);
      mDisplay.setCurrent(a, mTextBox);
    }


    // Decrypt the server response.
    String hex = new String(ciphertext);
    byte[] dehexed = HexCodec.hexToBytes(hex.toCharArray());
    byte[] deciphered = new byte[dehexed.length];
    mInCipher.processBytes(dehexed, 0, dehexed.length, deciphered, 0);

    String decipheredString = new String(deciphered);
    Alert a = new Alert("Response", decipheredString, null, null);
    a.setTimeout(Alert.FOREVER);
    mDisplay.setCurrent(a, mTextBox);
  }

  // Normally you would probably read keys from resource files
  //   in the MIDlet suite JAR, using the getResourceAsStream()
  //   method in Class. Here we just use hard-coded values that match
  //   the hard-coded values in StealthServlet.
  private byte[] getInKey() {
    return "Incoming MIDlet key".getBytes();
  }

  private byte[] getOutKey() {
    return "Outgoing MIDlet key".getBytes();
  }

  public void pauseApp() { }

  public void destroyApp(boolean unconditional) { }
}
```

When the user invokes the `Send` command, `StealthMIDlet` encrypts the user's message with its outgoing cipher. It then encodes the ciphertext as hexadecimal text in preparation for sending it to the servlet. The user's name and the ciphertext are packaged into a GET URL and sent to the server. Additionally, `StealthMIDlet` keeps track of a cookie that is used for session tracking. If the server sends back a session ID cookie, it is saved in `StealthMIDlet`'s `mSession` member variable. The saved cookie is sent with each subsequent request. This allows the server

to retrieve session information for this client. Without this session information, each HTTP request from client to server would need to reinitialize the ciphers so that they didn't get unsynchronized.

`StealthMIDlet` retrieves the response from the server as hexadecimal ciphertext. It converts the string to a byte array, and then decrypts the byte array using the MIDlet's incoming cipher. The decrypted message is displayed in an `Alert`.

`StealthMIDlet` makes use of the same `HexCodec` and `URLBuilder` classes that were presented earlier in this chapter. You will need to set the MIDlet property `StealthMIDlet-URL` to point to the location of the running `StealthServlet`.

On the server side, things are a little more complicated. `StealthServlet` should be capable of handling multiple clients, which means it should maintain a pair of ciphers for each user that connects. This is done using HTTP sessions, one session per user. When a client request comes in, `StealthServlet` attempts to find two ciphers in the user's session. If they don't exist, as will be the case the first time a user connects to the servlet, new ciphers are created. The ciphers are initialized using keys that are unique to each user. Exactly how these keys are located is left up to you. In this simple implementation, the `getInKey()` and `getOutKey()` methods are hard-coded.

You should notice that the keys on the servlet side appear to be reversed from the MIDlet. This is because the servlet's incoming cipher should decrypt using the same key as the MIDlet's outgoing cipher.

Once `StealthServlet` has located or created the ciphers that correspond to a particular user, it decrypts the incoming message and prints it out to the server console. Then it encrypts a response message (also hard-coded) and sends the response back to the MIDlet.

The entire `StealthServlet` class is shown in Listing 18-6.

Listing 18-6. *The Source Code for StealthServlet*

```
import javax.servlet.http.*;
import javax.servlet.*;
import java.io.*;
import java.util.*;

import org.bouncycastle.crypto.StreamCipher;
import org.bouncycastle.crypto.engines.RC4Engine;
import org.bouncycastle.crypto.params.KeyParameter;

public class StealthServlet extends HttpServlet {
  public void doGet(HttpServletRequest request,
      HttpServletResponse response)
      throws ServletException, IOException {
    String user = request.getParameter("user");

    // Try to find the user's cipher pair.
    HttpSession session = request.getSession();
    StreamCipher inCipher = (StreamCipher)session.getAttribute("inCipher");
    StreamCipher outCipher = (StreamCipher)session.getAttribute("outCipher");
```

```
    // If the ciphers aren't found, create and initialize a new pair.
    if (inCipher == null && outCipher == null) {
      // Retrieve the client's keys.
      byte[] inKey = getInKey(user);
      byte[] outKey = getOutKey(user);
      // Create and initialize the ciphers.
      inCipher = new RC4Engine();
      outCipher = new RC4Engine();
      inCipher.init(true, new KeyParameter(inKey));
      outCipher.init(false, new KeyParameter(outKey));
      // Now put them in the session object.
      session.setAttribute("inCipher", inCipher);
      session.setAttribute("outCipher", outCipher);
    }

    // Retrieve the client's message.
    String clientHex = request.getParameter("message");
    byte[] clientCiphertext = HexCodec.hexToBytes(clientHex);
    byte[] clientDecrypted = new byte[clientCiphertext.length];
    inCipher.processBytes(clientCiphertext, 0, clientCiphertext.length,
        clientDecrypted, 0);
    System.out.println("message = " + new String(clientDecrypted));

    // Create the response message.
    String message = "Hello, this is StealthServlet.";

    // Encrypt the message.
    byte[] plaintext = message.getBytes();
    byte[] ciphertext = new byte[plaintext.length];
    outCipher.processBytes(plaintext, 0, plaintext.length, ciphertext, 0);
    char[] hexCiphertext = HexCodec.bytesToHex(ciphertext);

    response.setContentType("text/plain");
    response.setContentLength(hexCiphertext.length);
    PrintWriter out = response.getWriter();
    out.println(hexCiphertext);
  }

  private byte[] getInKey(String user) {
    return "Outgoing MIDlet key".getBytes();
  }

private byte[] getOutKey(String user) {
    return "Incoming MIDlet key".getBytes();
  }
}
```

Suggested Enhancements

A few relatively minor enhancements would make this a serious application. The first area to tackle is key handling. `StealthMIDlet` should load its keys from resource files in the MIDlet suite JAR rather than using hard-coded values. This is possible using the `getResourceAsStream()` method in `Class`. The keys would probably be placed there at deployment time, which means the MIDlet would need to be deployed carefully, probably using HTTPS.

Likewise, `StealthServlet` should locate and load keys from a database or some kind of file repository. Something as simple as a standard naming scheme based on user names might be sufficient.

The keys themselves should be larger than the hard-coded samples here—how large is up to you. As long ago as 1996, the U.S. government was fairly sanguine about allowing the export of 40-bit RC4 technology, so you can rest assured that 40 bits is way too short. As the key length increases, of course, you may start to have memory or performance problems, particularly in a constrained environment like MIDP. Try to find a good balance between performance and security.

Furthermore, you might want to consider using a different algorithm, like Blowfish or Rijndael. The Bouncy Castle cryptography package has plenty of options in the `org.bouncycastle.crypto.engines` package. As we mentioned, you can treat a block cipher like a stream cipher using CFB mode.

Finally, the communication between the servlet and the MIDlet could be improved. It would be nice, for example, if the servlet had some way to tell the MIDlet it couldn't find a session. It's possible that the MIDlet will send up a cookie for a session that has expired on the server side. In the current implementation, the servlet will create a new set of ciphers, ones that are not synchronized with the MIDlet's ciphers. One way to solve this problem would be to have the servlet pass a response code to the MIDlet. One response code might mean, "I lost your session. Please reinitialize your ciphers and try again."

Deployment Issues

Suppose you dressed up this example and incorporated it into a product. What are the issues with distribution? For each copy of your software, you need to generate a pair of keys. These keys are stored as resource files inside the MIDlet suite JAR, which means that for each copy of your software, you'll need to generate a unique MIDlet suite JAR. At the same time, you need to save the keys on the server side somewhere. When the client MIDlet makes a connection, you need to be able to find the corresponding keys. None of this is particularly difficult, and it can be automated.

The MIDlet suite JAR contains keys that should be secret. Therefore, it is a security risk to transmit the JAR to a customer over the Internet. You might transfer it via HTTPS to a customer's browser, and then rely on that customer to install the MIDlet suite on a mobile telephone or other small device via a serial cable.

Trimming Bouncy Castle Down to Size

With both of the examples in this chapter, we're only using a small subset of the Bouncy Castle cryptography package. We use an obfuscator to trim out the pieces we don't need. A good obfuscator will find the methods, instance variables, and even entire classes that are not used

in an application and simply remove them. This is important with third-party libraries, with which you may only be using a fraction of the available functionality. Bouncy Castle includes all sorts of stuff that isn't used in `PasswordMIDlet` and `StealthMIDlet`.

There is another reason an obfuscator is necessary when using Bouncy Castle and some other third-party APIs. Bouncy Castle includes implementations of classes in the core `java.*` namespace, like `java.math.BigInteger`. MIDP implementations will fail to load classes from this namespace in an application. An obfuscator can be used to rename these classes out of the forbidden namespace.

The sample code from this chapter (available from the Downloads section of the Apress web site [`http:// www.apress.com`]) contains an Ant build file that invokes the ProGuard 3.2 obfuscator. ProGuard is an excellent piece of software. It is written entirely in Java and may be used freely. For more information, see `http://proguard.sourceforge.net/`.

The Ant target that runs ProGuard looks something like this:

```
<target name="obfuscate_proguard" depends="compile, copylib">
  <mkdir dir="build/proguard"/>
  <jar basedir="build/classes"
      jarfile="build/proguard/$wj2-crypto-input.jar"/>

  <java fork="yes" classname="proguard.ProGuard"
      classpath="${proguard}">
    <arg line="-libraryjars ${midp_lib}"/>
    <arg line="-injars build/proguard/${project}-input.jar"/>
    <arg line="-outjar build/proguard/${project}-output.jar"/>
    <arg line="-keep
        'public class * extends javax.microedition.midlet.MIDlet'"/>
    <arg line="-defaultpackage"/>
    <arg line="-dontusemixedcaseclassnames"/>
  </java>

  <mkdir dir="build/obfuscated"/>
  <unjar src="build/proguard/${project}-output.jar"
      dest="build/obfuscated"/>
</target>
```

ProGuard expects its input classes to be packaged in a JAR, so the first thing to do is create a JAR based on the package name, `wj2-crypto-input.jar`. Note that this JAR includes the Bouncy Castle classes.

Next, ProGuard is run by forking a Java process. The first argument, `-libraryjars`, tells ProGuard where to find the MIDP classes. The next argument, `-injars`, points ProGuard to the JAR of input files. The output file name is specified using `-outjar`. Next come three important options. It's important that the MIDlet classes themselves retain their names so that MIDlet management software on a device can load and run the classes. The `–keep` argument makes this happen for all subclasses of `MIDlet`. The package renaming (moving things out of `java.*`) is accomplished using the `-defaultpackage` argument. Finally, `-dontusemixedcaseclassnames` works around asinine behavior in Windows where obfuscated class files like *a.class* and *A.class* cannot exist in the same directory.

For more information on ProGuard and its options, consult the documentation, which is quite good. For another example of its use, see `http://developers.sun.com/techtopics/mobility/midp/articles/security3/`.

The results are impressive. Without the obfuscator, the MIDlet JAR containing `StealthMIDlet` is 699KB. After running ProGuard, the MIDlet JAR is 32KB and the offending `java.*` classes have been renamed to something innocuous.

Summary

Data security is crucial for some types of applications. Data security is feasible in the MIDP world using the Bouncy Castle cryptography package, which provides sophisticated, accessible, industrial-strength cryptography for the MIDP platform. This example presented two possible applications—one using a message digest for secure password authentication, and the other using ciphers to encrypt data sent between a MIDlet and a servlet.

Keep in mind that adding cryptography to an application or system won't necessarily make it more secure. You need to take a comprehensive system-level approach to security. Cryptography is just one of the tools in your box.

APPENDIX

MIDP API Reference

This appendix is a reference for the classes and interfaces of the MIDP API. This reference is designed to help you quickly find the signature of a method in the MIDP API. Exceptions and errors are not included. Optional APIs are not included.

For a full description of any class, interface, or method, consult the API documentation, either in HTML (usually distributed with a MIDP toolkit) or in the MIDP specification itself.

The API listings are alphabetical, grouped by package.

This reference covers MIDP 2.0, CLDC 1.0, and CLDC 1.1. Methods that are new in CLDC 1.1 are marked with a plus sign (+). You will find implementations of MIDP 2.0 paired with either CLDC 1.0 or CLDC 1.1 on currently available devices; keep this in mind as you browse the reference.

Package java.io

Class java.io.ByteArrayInputStream

```
public class ByteArrayInputStream
    extends java.io.InputStream {
  // Constructors
  public ByteArrayInputStream(byte[] buf);
  public ByteArrayInputStream(byte[] buf, int offset, int length);

  // Methods
  public synchronized int available();
  public synchronized void close();
  public void mark(int readAheadLimit);
  public boolean markSupported();
  public synchronized int read();
  public synchronized int read(byte[] b, int off, int len);
  public synchronized void reset();
  public synchronized long skip(long n);
}
```

Class java.io.ByteArrayOutputStream

```
public class ByteArrayOutputStream
    extends java.io.OutputStream {
  // Constructors
  public ByteArrayOutputStream();
  public ByteArrayOutputStream(int size);

  // Methods
  public synchronized void close();
  public synchronized void reset();
  public int size();
  public synchronized byte[] toByteArray();
  public String toString();
  public synchronized void write(int b);
  public synchronized void write(byte[] b, int off, int len);
}
```

Interface java.io.DataInput

```
public interface DataInput {
  // Methods
  public boolean readBoolean();
  public byte readByte();
  public char readChar();
+ public double readDouble();
+ public float readFloat();
  public void readFully(byte[] b);
  public void readFully(byte[] b, int off, int len);
  public int readInt();
  public long readLong();
  public short readShort();
  public String readUTF();
  public int readUnsignedByte();
  public int readUnsignedShort();
  public int skipBytes(int n);
}
```

Class java.io.DataInputStream

```
public class DataInputStream
    extends java.io.InputStream
    implements DataInput {
  // Static methods
  public static final String readUTF(DataInput in);
```

```
    // Constructors
    public DataInputStream(InputStream in);

    // Methods
    public int available();
    public void close();
    public synchronized void mark(int readlimit);
    public boolean markSupported();
    public int read();
    public final int read(byte[] b);
    public final int read(byte[] b, int off, int len);
    public final boolean readBoolean();
    public final byte readByte();
    public final char readChar();
+   public final double readDouble();
+   public final float readFloat();
    public final void readFully(byte[] b);
    public final void readFully(byte[] b, int off, int len);
    public final int readInt();
    public final long readLong();
    public final short readShort();
    public final String readUTF();
    public final int readUnsignedByte();
    public final int readUnsignedShort();
    public synchronized void reset();
    public long skip(long n);
    public final int skipBytes(int n);
  }
```

Interface java.io.DataOutput

```
  public interface DataOutput {
    // Methods
    public void write(int b);
    public void write(byte[] b);
    public void write(byte[] b, int off, int len);
    public void writeBoolean(boolean v);
    public void writeByte(int v);
    public void writeChar(int v);
    public void writeChars(String s);
+   public void writeDouble(double v);
+   public void writeFloat(float v);
    public void writeInt(int v);
    public void writeLong(long v);
    public void writeShort(int v);
    public void writeUTF(String str);
  }
```

Class java.io.DataOutputStream

```
  public class DataOutputStream
      extends java.io.OutputStream
      implements DataOutput {
    // Constructors
    public DataOutputStream(OutputStream out);

    // Methods
    public void close();
    public void flush();
    public void write(int b);
    public void write(byte[] b, int off, int len);
    public final void writeBoolean(boolean v);
    public final void writeByte(int v);
    public final void writeChar(int v);
    public final void writeChars(String s);
+   public final void writeDouble(double v);
+   public final void writeFloat(float v);
    public final void writeInt(int v);
    public final void writeLong(long v);
    public final void writeShort(int v);
    public final void writeUTF(String str);
  }
```

Class java.io.InputStream

```
  public abstract class InputStream
      extends java.lang.Object {
    // Constructors
    public InputStream();

    // Methods
    public int available();
    public void close();
    public synchronized void mark(int readlimit);
    public boolean markSupported();
    public abstract int read();
    public int read(byte[] b);
    public int read(byte[] b, int off, int len);
    public synchronized void reset();
    public long skip(long n);
  }
```

Class java.io.InputStreamReader

```
public class InputStreamReader
    extends java.io.Reader {
  // Constructors
  public InputStreamReader(InputStream is);
  public InputStreamReader(InputStream is, String enc);

  // Methods
  public void close();
  public void mark(int readAheadLimit);
  public boolean markSupported();
  public int read();
  public int read(char[] cbuf, int off, int len);
  public boolean ready();
  public void reset();
  public long skip(long n);
}
```

Class java.io.OutputStream

```
public abstract class OutputStream
    extends java.lang.Object {
  // Constructors
  public OutputStream();

  // Methods
  public void close();
  public void flush();
  public abstract void write(int b);
  public void write(byte[] b);
  public void write(byte[] b, int off, int len);
}
```

Class java.io.OutputStreamWriter

```
public class OutputStreamWriter
    extends java.io.Writer {
  // Constructors
  public OutputStreamWriter(OutputStream os);
  public OutputStreamWriter(OutputStream os, String enc);

  // Methods
  public void close();
  public void flush();
  public void write(int c);
  public void write(char[] cbuf, int off, int len);
  public void write(String str, int off, int len);
}
```

Class java.io.PrintStream

```
public class PrintStream
    extends java.io.OutputStream {
  // Constructors
  public PrintStream(OutputStream out);

  // Methods
  public boolean checkError();
  public void close();
  public void flush();
  public void print(boolean b);
  public void print(char c);
  public void print(int i);
  public void print(long l);
+ public void print(float f);
+ public void print(double d);
  public void print(char[] s);
  public void print(String s);
  public void print(Object obj);
  public void println();
  public void println(boolean x);
  public void println(char x);
  public void println(int x);
  public void println(long x);
+ public void println(float x);
+ public void println(double x);
  public void println(char[] x);
  public void println(String x);
  public void println(Object x);
  protected void setError();
  public void write(int b);
  public void write(byte[] buf, int off, int len);
}
```

Class java.io.Reader

```
public abstract class Reader
    extends java.lang.Object {
  // Constructors
  protected Reader();
  protected Reader(Object lock);

  // Methods
  public abstract void close();
  public void mark(int readAheadLimit);
  public boolean markSupported();
```

```
    public int read();
    public int read(char[] cbuf);
    public abstract int read(char[] cbuf, int off, int len);
    public boolean ready();
    public void reset();
    public long skip(long n);
  }
```

Class java.io.Writer

```
  public abstract class Writer
      extends java.lang.Object {
    // Constructors
    protected Writer();
    protected Writer(Object lock);

    // Methods
    public abstract void close();
    public abstract void flush();
    public void write(int c);
    public void write(char[] cbuf);
    public abstract void write(char[] cbuf, int off, int len);
    public void write(String str);
    public void write(String str, int off, int len);
  }
```

Package java.lang

Class java.lang.Boolean

```
  public final class Boolean
      extends java.lang.Object {
    // Constants
+   public static final Boolean FALSE;
+   public static final Boolean TRUE;

    // Constructors
    public Boolean(boolean value);

    // Methods
    public boolean booleanValue();
    public boolean equals(Object obj);
    public int hashCode();
    public String toString();
  }
```

Class java.lang.Byte

```
public final class Byte
    extends java.lang.Object {
  // Constants
  public static final byte MAX_VALUE;
  public static final byte MIN_VALUE;

  // Static methods
  public static byte parseByte(String s);
  public static byte parseByte(String s, int radix);

  // Constructors
  public Byte(byte value);

  // Methods
  public byte byteValue();
  public boolean equals(Object obj);
  public int hashCode();
  public String toString();
}
```

Class java.lang.Character

```
public final class Character
    extends java.lang.Object {
  // Constants
  public static final int MAX_RADIX;
  public static final char MAX_VALUE;
  public static final int MIN_RADIX;
  public static final char MIN_VALUE;

  // Static methods
  public static int digit(char ch, int radix);
  public static boolean isDigit(char ch);
  public static boolean isLowerCase(char ch);
  public static boolean isUpperCase(char ch);
  public static char toLowerCase(char ch);
  public static char toUpperCase(char ch);

  // Constructors
  public Character(char value);
```

```
    // Methods
    public char charValue();
    public boolean equals(Object obj);
    public int hashCode();
    public String toString();
  }
```

Class java.lang.Class

```
  public final class Class
      extends java.lang.Object {
    // Static methods
    public static native Class forName(String className);

    // Methods
    public native String getName();
    public InputStream getResourceAsStream(String name);
    public native boolean isArray();
    public native boolean isAssignableFrom(Class cls);
    public native boolean isInstance(Object obj);
    public native boolean isInterface();
    public native Object newInstance();
    public String toString();
  }
```

Class java.lang.Double

```
+ public final class Double
      extends java.lang.Object {
    // Constants
+   public static final double MAX_VALUE;
+   public static final double MIN_VALUE;
+   public static final double NEGATIVE_INFINITY;
+   public static final double NaN;
+   public static final double POSITIVE_INFINITY;

    // Static methods
+   public static native long doubleToLongBits(double value);
+   public static boolean isInfinite(double v);
+   public static boolean isNaN(double v);
+   public static native double longBitsToDouble(long bits);
+   public static double parseDouble(String s);
+   public static String toString(double d);
+   public static Double valueOf(String s);
```

```
    // Constructors
+   public Double(double value);

    // Methods
+   public byte byteValue();
+   public double doubleValue();
+   public boolean equals(Object obj);
+   public float floatValue();
+   public int hashCode();
+   public int intValue();
+   public boolean isInfinite();
+   public boolean isNaN();
+   public long longValue();
+   public short shortValue();
+   public String toString();
  }
```

Class java.lang.Float

```
+ public final class Float
      extends java.lang.Object {
    // Constants
+   public static final float MAX_VALUE;
+   public static final float MIN_VALUE;
+   public static final float NEGATIVE_INFINITY;
+   public static final float NaN;
+   public static final float POSITIVE_INFINITY;

    // Static methods
+   public static native int floatToIntBits(float value);
+   public static native float intBitsToFloat(int bits);
+   public static boolean isInfinite(float v);
+   public static boolean isNaN(float v);
+   public static float parseFloat(String s);
+   public static String toString(float f);
+   public static Float valueOf(String s);

    // Constructors
+   public Float(float value);
+   public Float(double value);
```

```
    // Methods
+   public byte byteValue();
+   public double doubleValue();
+   public boolean equals(Object obj);
+   public float floatValue();
+   public int hashCode();
+   public int intValue();
+   public boolean isInfinite();
+   public boolean isNaN();
+   public long longValue();
+   public short shortValue();
+   public String toString();
  }
```

Class java.lang.Integer

```
  public final class Integer
      extends java.lang.Object {
    // Constants
    public static final int MAX_VALUE;
    public static final int MIN_VALUE;

    // Static methods
    public static int parseInt(String s, int radix);
    public static int parseInt(String s);
    public static String toBinaryString(int i);
    public static String toHexString(int i);
    public static String toOctalString(int i);
    public static String toString(int i, int radix);
    public static String toString(int i);
    public static Integer valueOf(String s, int radix);
    public static Integer valueOf(String s);

    // Constructors
    public Integer(int value);

    // Methods
    public byte byteValue();
+   public double doubleValue();
    public boolean equals(Object obj);
+   public float floatValue();
    public int hashCode();
    public int intValue();
    public long longValue();
    public short shortValue();
    public String toString();
  }
```

Class java.lang.Long

```
  public final class Long
      extends java.lang.Object {
    // Constants
    public static final long MAX_VALUE;
    public static final long MIN_VALUE;

    // Static methods
    public static long parseLong(String s, int radix);
    public static long parseLong(String s);
    public static String toString(long i, int radix);
    public static String toString(long i);

    // Constructors
    public Long(long value);

    // Methods
+   public double doubleValue();
    public boolean equals(Object obj);
+   public float floatValue();
    public int hashCode();
    public long longValue();
    public String toString();
  }
```

Class java.lang.Math

```
  public final class Math
      extends java.lang.Object {
    // Constants
+   public static final double E;
+   public static final double PI;


    // Static methods
    public static int abs(int a);
    public static long abs(long a);
+   public static float abs(float a);
+   public static double abs(double a);
+   public static native double ceil(double a);
+   public static native double cos(double a);
+   public static native double floor(double a);
    public static int max(int a, int b);
    public static long max(long a, long b);
+   public static float max(float a, float b);
+   public static double max(double a, double b);
    public static int min(int a, int b);
```

```
    public static long min(long a, long b);
+   public static float min(float a, float b);
+   public static double min(double a, double b);
+   public static native double sin(double a);
+   public static native double sqrt(double a);
+   public static native double tan(double a);
+   public static double toDegrees(double angrad);
+   public static double toRadians(double angdeg);
  }
```

Class java.lang.Object

```
public class Object {
  // Constructors
  public Object();

  // Methods
  public boolean equals(Object obj);
  public final native Class getClass();
  public native int hashCode();
  public final native void notify();
  public final native void notifyAll();
  public String toString();
  public final native void wait(long timeout);
  public final void wait(long timeout, int nanos);
  public final void wait();
}
```

Interface java.lang.Runnable

```
public interface Runnable {
  // Methods
  public void run();
}
```

Class java.lang.Runtime

```
public class Runtime
    extends java.lang.Object {
  // Static methods
  public static Runtime getRuntime();

  // Methods
  public void exit(int status);
  public native long freeMemory();
  public native void gc();
  public native long totalMemory();
}
```

Class java.lang.Short

```
public final class Short
    extends java.lang.Object {
  // Constants
  public static final short MAX_VALUE;
  public static final short MIN_VALUE;

  // Static methods
  public static short parseShort(String s);
  public static short parseShort(String s, int radix);

  // Constructors
  public Short(short value);

  // Methods
  public boolean equals(Object obj);
  public int hashCode();
  public short shortValue();
  public String toString();
}
```

Class java.lang.String

```
public final class String
    extends java.lang.Object {
  // Static methods
  public static String valueOf(Object obj);
  public static String valueOf(char[] data);
  public static String valueOf(char[] data, int offset, int count);
  public static String valueOf(boolean b);
  public static String valueOf(char c);
  public static String valueOf(int i);
  public static String valueOf(long l);
+ public static String valueOf(float f);
+ public static String valueOf(double d);

  // Constructors
  public String();
  public String(String value);
  public String(char[] value);
  public String(char[] value, int offset, int count);
  public String(byte[] bytes, int off, int len, String enc);
  public String(byte[] bytes, String enc);
  public String(byte[] bytes, int off, int len);
  public String(byte[] bytes);
  public String(StringBuffer buffer);
```

```
    // Methods
    public native char charAt(int index);
    public int compareTo(String anotherString);
    public String concat(String str);
    public boolean endsWith(String suffix);
    public native boolean equals(Object anObject);
+   public boolean equalsIgnoreCase(String anotherString);
    public byte[] getBytes(String enc);
    public byte[] getBytes();
    public void getChars(int srcBegin, int srcEnd, char[] dst, int dstBegin);
    public int hashCode();
    public native int indexOf(int ch);
    public native int indexOf(int ch, int fromIndex);
    public int indexOf(String str);
    public int indexOf(String str, int fromIndex);
+   public native String intern();
    public int lastIndexOf(int ch);
    public int lastIndexOf(int ch, int fromIndex);
    public int length();
    public boolean regionMatches(boolean ignoreCase, int toffset,
        String other, int ooffset, int len);
    public String replace(char oldChar, char newChar);
    public boolean startsWith(String prefix, int toffset);
    public boolean startsWith(String prefix);
    public String substring(int beginIndex);
    public String substring(int beginIndex, int endIndex);
    public char[] toCharArray();
    public String toLowerCase();
    public String toString();
    public String toUpperCase();
    public String trim();
  }
```

Class java.lang.StringBuffer

```
  public final class StringBuffer
      extends java.lang.Object {
    // Constructors
    public StringBuffer();
    public StringBuffer(int length);
    public StringBuffer(String str);

    // Methods
    public synchronized StringBuffer append(Object obj);
    public native synchronized StringBuffer append(String str);
    public synchronized StringBuffer append(char[] str);
    public synchronized StringBuffer append(char[] str, int offset, int len);
```

```
    public StringBuffer append(boolean b);
    public synchronized StringBuffer append(char c);
    public native StringBuffer append(int i);
    public StringBuffer append(long l);
+   public StringBuffer append(float f);
+   public StringBuffer append(double d);
    public int capacity();
    public synchronized char charAt(int index);
    public synchronized StringBuffer delete(int start, int end);
    public synchronized StringBuffer deleteCharAt(int index);
    public synchronized void ensureCapacity(int minimumCapacity);
    public synchronized void getChars(int srcBegin, int srcEnd,
        char[] dst, int dstBegin);
    public synchronized StringBuffer insert(int offset, Object obj);
    public synchronized StringBuffer insert(int offset, String str);
    public synchronized StringBuffer insert(int offset, char[] str);
    public StringBuffer insert(int offset, boolean b);
    public synchronized StringBuffer insert(int offset, char c);
    public StringBuffer insert(int offset, int i);
    public StringBuffer insert(int offset, long l);
+   public StringBuffer insert(int offset, float f);
+   public StringBuffer insert(int offset, double d);
    public int length();
    public synchronized StringBuffer reverse();
    public synchronized void setCharAt(int index, char ch);
    public synchronized void setLength(int newLength);
    public native String toString();
  }
```

Class java.lang.System

```
  public final class System
      extends java.lang.Object {
    // Constants
    public static final PrintStream err;
    public static final PrintStream out;

    // Static methods
    public static native void arraycopy(Object src, int src_position,
        Object dst, int dst_position, int length);
    public static native long currentTimeMillis();
    public static void exit(int status);
    public static void gc();
    public static String getProperty(String key);
    public static native int identityHashCode(Object x);
  }
```

Class java.lang.Thread

```
  public class Thread
      extends java.lang.Object
      implements Runnable {
    // Constants
    public static final int MAX_PRIORITY;
    public static final int MIN_PRIORITY;
    public static final int NORM_PRIORITY;

    // Static methods
    public static native int activeCount();
    public static native Thread currentThread();
    public static native void sleep(long millis);
    public static native void yield();

    // Constructors
    public Thread();
+   public Thread(String name);
    public Thread(Runnable target);
+   public Thread(Runnable target, String name);

    // Methods
+   public final String getName();
    public final int getPriority();
+   public void interrupt();
    public final native boolean isAlive();
    public final void join();
    public void run();
    public final void setPriority(int newPriority);
    public native synchronized void start();
    public String toString();
  }
```

Class java.lang.Throwable

```
  public class Throwable
      extends java.lang.Object {
    // Constructors
    public Throwable();
    public Throwable(String message);

    // Methods
    public String getMessage();
    public void printStackTrace();
    public String toString();
  }
```

Package java.lang.ref

Class java.lang.ref.Reference

```
+ public abstract class Reference
      extends java.lang.Object {
    // Methods
+   public void clear();
+   public Object get();
  }
```

Class java.lang.ref.WeakReference

```
+ public class WeakReference
      extends java.lang.ref.Reference {
    // Constructors
+   public WeakReference(Object ref);
  }
```

Package java.util

Class java.util.Calendar

```
  public abstract class Calendar
      extends java.lang.Object {
    // Constants
    public static final int AM;
    public static final int AM_PM;
    public static final int APRIL;
    public static final int AUGUST;
    public static final int DATE;
    public static final int DAY_OF_MONTH;
    public static final int DAY_OF_WEEK;
    public static final int DECEMBER;
    public static final int FEBRUARY;
    public static final int FRIDAY;
    public static final int HOUR;
    public static final int HOUR_OF_DAY;
    public static final int JANUARY;
    public static final int JULY;
    public static final int JUNE;
    public static final int MARCH;
    public static final int MAY;
```

```
    public static final int MILLISECOND;
    public static final int MINUTE;
    public static final int MONDAY;
    public static final int MONTH;
    public static final int NOVEMBER;
    public static final int OCTOBER;
    public static final int PM;
    public static final int SATURDAY;
    public static final int SECOND;
    public static final int SEPTEMBER;
    public static final int SUNDAY;
    public static final int THURSDAY;
    public static final int TUESDAY;
    public static final int WEDNESDAY;
    public static final int YEAR;

    // Static methods
    public static synchronized Calendar getInstance();
    public static synchronized Calendar getInstance(TimeZone zone);

    // Constructors
    protected Calendar();

    // Methods
    public boolean after(Object when);
    public boolean before(Object when);
+   protected abstract void computeFields();
+   protected abstract void computeTime();
    public boolean equals(Object obj);
    public final int get(int field);
    public final Date getTime();
    protected long getTimeInMillis();
    public TimeZone getTimeZone();
    public final void set(int field, int value);
    public final void setTime(Date date);
    protected void setTimeInMillis(long millis);
    public void setTimeZone(TimeZone value);
  }
```

Class java.util.Date

```
  public class Date
      extends java.lang.Object {
    // Constructors
    public Date();
    public Date(long date);
```

```
  // Methods
  public boolean equals(Object obj);
  public long getTime();
  public int hashCode();
  public void setTime(long time);
}
```

Interface java.util.Enumeration

```
public interface Enumeration {
  // Methods
  public boolean hasMoreElements();
  public Object nextElement();
}
```

Class java.util.Hashtable

```
public class Hashtable
    extends java.lang.Object {
  // Constructors
  public Hashtable(int initialCapacity);
  public Hashtable();

  // Methods
  public synchronized void clear();
  public synchronized boolean contains(Object value);
  public synchronized boolean containsKey(Object key);
  public synchronized Enumeration elements();
  public synchronized Object get(Object key);
  public boolean isEmpty();
  public synchronized Enumeration keys();
  public synchronized Object put(Object key, Object value);

  protected void rehash();
  public synchronized Object remove(Object key);
  public int size();
  public synchronized String toString();
}
```

Class java.util.Random

```
public class Random
    extends java.lang.Object {
  // Constructors
  public Random();
  public Random(long seed);
```

```
    // Methods
    protected synchronized int next(int bits);
+   public double nextDouble();
+   public float nextFloat();
    public int nextInt();
+   public int nextInt(int n);
    public long nextLong();
    public synchronized void setSeed(long seed);
  }
```

Class java.util.Stack

```
  public class Stack
      extends java.util.Vector {
    // Constructors
    public Stack();

    // Methods
    public boolean empty();
    public synchronized Object peek();
    public synchronized Object pop();
    public Object push(Object item);
    public synchronized int search(Object o);
  }
```

Class java.util.Timer

```
  public class Timer
      extends java.lang.Object {
    // Constructors
    public Timer();

    // Methods
    public void cancel();
    public void schedule(TimerTask task, long delay);
    public void schedule(TimerTask task, Date time);
    public void schedule(TimerTask task, long delay, long period);
    public void schedule(TimerTask task, Date firstTime, long period);
    public void scheduleAtFixedRate(TimerTask task, long delay, long period);
    public void scheduleAtFixedRate(TimerTask task, Date firstTime,
        long period);
  }
```

Class java.util.TimerTask

```
public abstract class TimerTask
    extends java.lang.Object
    implements Runnable {
  // Constructors
  protected TimerTask();

  // Methods
  public boolean cancel();
  public abstract void run();
  public long scheduledExecutionTime();
}
```

Class java.util.TimeZone

```
public abstract class TimeZone
    extends java.lang.Object {
  // Static methods
  public static String getAvailableIDs();
  public static synchronized TimeZone getDefault();
  public static synchronized TimeZone getTimeZone(String ID);

  // Constructors
  public TimeZone();

  // Methods
  public String getID();
  public abstract int getOffset(int era, int year, int month,
      int day, int dayOfWeek, int millis);
  public abstract int getRawOffset();
  public abstract boolean useDaylightTime();
}
```

Class java.util.Vector

```
public class Vector
    extends java.lang.Object {
  // Constructors
  public Vector(int initialCapacity, int capacityIncrement);
  public Vector(int initialCapacity);
  public Vector();
```

```
    // Methods
    public synchronized void addElement(Object obj);
    public int capacity();
    public boolean contains(Object elem);
    public synchronized void copyInto(Object[] anArray);
    public synchronized Object elementAt(int index);
    public synchronized Enumeration elements();
    public synchronized void ensureCapacity(int minCapacity);
    public synchronized Object firstElement();
    public int indexOf(Object elem);
    public synchronized int indexOf(Object elem, int index);
    public synchronized void insertElementAt(Object obj, int index);
    public boolean isEmpty();
    public synchronized Object lastElement();
    public int lastIndexOf(Object elem);
    public synchronized int lastIndexOf(Object elem, int index);
    public synchronized void removeAllElements();
    public synchronized boolean removeElement(Object obj);
    public synchronized void removeElementAt(int index);
    public synchronized void setElementAt(Object obj, int index);
    public synchronized void setSize(int newSize);
    public int size();
    public synchronized String toString();
    public synchronized void trimToSize();
  }
```

Package javax.microedition.io

Interface javax.microedition.io.CommConnection

```
public interface CommConnection
      implements StreamConnection {
    // Methods
   public int getBaudRate();
   public int setBaudRate(int baudrate);
  }
```

Class javax.microedition.io.Connector

```
  public class Connector
      extends java.lang.Object {
    // Constants
    public static final int READ;
    public static final int READ_WRITE;
    public static final int WRITE;
```

```
  // Static methods
  public static Connection open(String name);
  public static Connection open(String name, int mode);
  public static Connection open(String name, int mode, boolean timeouts);
  public static DataInputStream openDataInputStream(String name);
  public static DataOutputStream openDataOutputStream(String name);
  public static InputStream openInputStream(String name);
  public static OutputStream openOutputStream(String name);
}
```

Interface javax.microedition.io.Connection

```
public interface Connection {
  // Methods
  public void close();
}
```

Interface javax.microedition.io.ContentConnection

```
public interface ContentConnection
    implements StreamConnection {
  // Methods
  public String getEncoding();
  public long getLength();
  public String getType();
}
```

Interface javax.microedition.io.Datagram

```
public interface Datagram
    implements DataInput, DataOutput {
  // Methods
  public String getAddress();
  public byte[] getData();
  public int getLength();
  public int getOffset();
  public void reset();
  public void setAddress(String addr);
  public void setAddress(Datagram reference);
  public void setData(byte[] buffer, int offset, int len);
  public void setLength(int len);
}
```

Interface javax.microedition.io.DatagramConnection

```
public interface DatagramConnection
    implements Connection {
```

```
  // Methods
  public int getMaximumLength();
  public int getNominalLength();
  public Datagram newDatagram(int size);
  public Datagram newDatagram(int size, String addr);
  public Datagram newDatagram(byte[] buf, int size);
  public Datagram newDatagram(byte[] buf, int size, String addr);
  public void receive(Datagram dgram);
  public void send(Datagram dgram);
}
```

Interface javax.microedition.io.HttpConnection

```
public interface HttpConnection
    implements ContentConnection {
  // Constants
  public static final String GET;
  public static final String HEAD;
  public static final int HTTP_ACCEPTED;
  public static final int HTTP_BAD_GATEWAY;
  public static final int HTTP_BAD_METHOD;
  public static final int HTTP_BAD_REQUEST;
  public static final int HTTP_CLIENT_TIMEOUT;
  public static final int HTTP_CONFLICT;
  public static final int HTTP_CREATED;
  public static final int HTTP_ENTITY_TOO_LARGE;
  public static final int HTTP_EXPECT_FAILED;
  public static final int HTTP_FORBIDDEN;
  public static final int HTTP_GATEWAY_TIMEOUT;
  public static final int HTTP_GONE;
  public static final int HTTP_INTERNAL_ERROR;
  public static final int HTTP_LENGTH_REQUIRED;
  public static final int HTTP_MOVED_PERM;
  public static final int HTTP_MOVED_TEMP;
  public static final int HTTP_MULT_CHOICE;
  public static final int HTTP_NOT_ACCEPTABLE;
  public static final int HTTP_NOT_AUTHORITATIVE;
  public static final int HTTP_NOT_FOUND;
  public static final int HTTP_NOT_IMPLEMENTED;
  public static final int HTTP_NOT_MODIFIED;
  public static final int HTTP_NO_CONTENT;
  public static final int HTTP_OK;
  public static final int HTTP_PARTIAL;
  public static final int HTTP_PAYMENT_REQUIRED;
  public static final int HTTP_PRECON_FAILED;
  public static final int HTTP_PROXY_AUTH;
  public static final int HTTP_REQ_TOO_LONG;
```

```
    public static final int HTTP_RESET;
    public static final int HTTP_SEE_OTHER;
    public static final int HTTP_TEMP_REDIRECT;
    public static final int HTTP_UNAUTHORIZED;
    public static final int HTTP_UNAVAILABLE;
    public static final int HTTP_UNSUPPORTED_RANGE;
    public static final int HTTP_UNSUPPORTED_TYPE;
    public static final int HTTP_USE_PROXY;
    public static final int HTTP_VERSION;
    public static final String POST;

    // Methods
    public long getDate();
    public long getExpiration();
    public String getFile();
    public String getHeaderField(String name);
    public String getHeaderField(int n);
    public long getHeaderFieldDate(String name, long def);
    public int getHeaderFieldInt(String name, int def);
    public String getHeaderFieldKey(int n);
    public String getHost();
    public long getLastModified();
    public int getPort();
    public String getProtocol();
    public String getQuery();
    public String getRef();
    public String getRequestMethod();
    public String getRequestProperty(String key);
    public int getResponseCode();
    public String getResponseMessage();
    public String getURL();
    public void setRequestMethod(String method);
    public void setRequestProperty(String key, String value);
  }
```

Interface javax.microedition.io.HttpsConnection

```
public interface HttpsConnection
     implements HttpConnection {
    // Methods
   public int getPort();
   public SecurityInfo getSecurityInfo();
  }
```

Interface javax.microedition.io.InputConnection

```
public interface InputConnection
    implements Connection {
  // Methods
  public DataInputStream openDataInputStream();
  public InputStream openInputStream();
}
```

Interface javax.microedition.io.OutputConnection

```
public interface OutputConnection
    implements Connection {
  // Methods
  public DataOutputStream openDataOutputStream();
  public OutputStream openOutputStream();
}
```

Class javax.microedition.io.PushRegistry

```
public class PushRegistry
     extends java.lang.Object {
   // Static methods
  public static String getFilter(String connection);
  public static String getMIDlet(String connection);
  public static String listConnections(boolean available);
  public static long registerAlarm(String midlet, long time);
  public static void registerConnection(String connection,
       String midlet, String filter);
  public static boolean unregisterConnection(String connection);
}
```

Interface javax.microedition.io.SecureConnection

```
public interface SecureConnection
     implements SocketConnection {
   // Methods
  public SecurityInfo getSecurityInfo();
}
```

Interface javax.microedition.io.SecurityInfo

```
public interface SecurityInfo {
   // Methods
  public String getCipherSuite();
  public String getProtocolName();
  public String getProtocolVersion();
  public Certificate getServerCertificate();
 }
```

Interface javax.microedition.io.ServerSocketConnection

```
public interface ServerSocketConnection
     implements StreamConnectionNotifier {
   // Methods
  public String getLocalAddress();
  public int getLocalPort();
 }
```

Interface javax.microedition.io.SocketConnection

```
public interface SocketConnection
     implements StreamConnection {
   // Constants
  public static final byte DELAY;
  public static final byte KEEPALIVE;
  public static final byte LINGER;
  public static final byte RCVBUF;
  public static final byte SNDBUF;

   // Methods
  public String getAddress();
  public String getLocalAddress();
  public int getLocalPort();
  public int getPort();
  public int getSocketOption(byte option);
  public void setSocketOption(byte option, int value);
 }
```

Interface javax.microedition.io.StreamConnection

```
 public interface StreamConnection
     implements InputConnection, OutputConnection {
 }
```

Interface javax.microedition.io.StreamConnectionNotifier

```
public interface StreamConnectionNotifier
    implements Connection {
  // Methods
  public StreamConnection acceptAndOpen();
}
```

Interface javax.microedition.io.UDPDatagramConnection

```
public interface UDPDatagramConnection
     implements DatagramConnection {
   // Methods
  public String getLocalAddress();
  public int getLocalPort();
 }
```

Package javax.microedition.lcdui

Class javax.microedition.lcdui.Alert

```
public class Alert
    extends javax.microedition.lcdui.Screen {
  // Constants
  public static final Command DISMISS_COMMAND;
  public static final int FOREVER;

  // Constructors
  public Alert(String title);
  public Alert(String title, String alertText, Image alertImage,
      AlertType alertType);


  // Methods
  public void addCommand(Command cmd);
  public int getDefaultTimeout();
  public Image getImage();
  public Gauge getIndicator();
  public String getString();
  public int getTimeout();
  public AlertType getType();
  public void removeCommand(Command cmd);
```

```
  public void setCommandListener(CommandListener l);
  public void setImage(Image img);
  public void setIndicator(Gauge indicator);
  public void setString(String str);
  public void setTimeout(int time);
  public void setType(AlertType type);
}
```

Class javax.microedition.lcdui.AlertType

```
public class AlertType
    extends java.lang.Object {
  // Constants
  public static final AlertType ALARM;
  public static final AlertType CONFIRMATION;
  public static final AlertType ERROR;
  public static final AlertType INFO;
  public static final AlertType WARNING;

  // Constructors
  protected AlertType();

  // Methods
  public boolean playSound(Display display);
}
```

Class javax.microedition.lcdui.Canvas

```
public abstract class Canvas
    extends javax.microedition.lcdui.Displayable {
  // Constants
  public static final int DOWN;
  public static final int FIRE;
  public static final int GAME_A;
  public static final int GAME_B;
  public static final int GAME_C;
  public static final int GAME_D;
  public static final int KEY_NUM0;
  public static final int KEY_NUM1;
  public static final int KEY_NUM2;
  public static final int KEY_NUM3;
  public static final int KEY_NUM4;
  public static final int KEY_NUM5;
  public static final int KEY_NUM6;
  public static final int KEY_NUM7;
  public static final int KEY_NUM8;
  public static final int KEY_NUM9;
```

```
  public static final int KEY_POUND;
  public static final int KEY_STAR;
  public static final int LEFT;
  public static final int RIGHT;
  public static final int UP;

  // Constructors
  protected Canvas();

  // Methods
  public int getGameAction(int keyCode);

  public int getKeyCode(int gameAction);
  public String getKeyName(int keyCode);

  public boolean hasPointerEvents();
  public boolean hasPointerMotionEvents();
  public boolean hasRepeatEvents();
  protected void hideNotify();
  public boolean isDoubleBuffered();
  protected void keyPressed(int keyCode);
  protected void keyReleased(int keyCode);
  protected void keyRepeated(int keyCode);
  protected abstract void paint(Graphics g);
  protected void pointerDragged(int x, int y);
  protected void pointerPressed(int x, int y);
  protected void pointerReleased(int x, int y);
  public final void repaint(int x, int y, int width, int height);
  public final void repaint();
  public final void serviceRepaints();
  public void setFullScreenMode(boolean mode);
  protected void showNotify();
  protected void sizeChanged(int w, int h);
}
```

Interface javax.microedition.lcdui.Choice

```
public interface Choice {
  // Constants
  public static final int EXCLUSIVE;
  public static final int IMPLICIT;
  public static final int MULTIPLE;
  public static final int POPUP;
  public static final int TEXT_WRAP_DEFAULT;
  public static final int TEXT_WRAP_OFF;
  public static final int TEXT_WRAP_ON;
```

```
  // Methods
  public int append(String stringPart, Image imagePart);
  public void delete(int elementNum);
  public void deleteAll();
  public int getFitPolicy();
  public Font getFont(int elementNum);
  public Image getImage(int elementNum);
  public int getSelectedFlags(boolean[] selectedArray_return);
  public int getSelectedIndex();
  public String getString(int elementNum);
  public void insert(int elementNum, String stringPart, Image imagePart);
  public boolean isSelected(int elementNum);
  public void set(int elementNum, String stringPart, Image imagePart);
  public void setFitPolicy(int fitPolicy);
  public void setFont(int elementNum, Font font);
  public void setSelectedFlags(boolean[] selectedArray);
  public void setSelectedIndex(int elementNum, boolean selected);
  public int size();
}
```

Class javax.microedition.lcdui.ChoiceGroup

```
public class ChoiceGroup
    extends javax.microedition.lcdui.Item
    implements Choice {
  // Constructors
  public ChoiceGroup(String label, int choiceType);
  public ChoiceGroup(String label, int choiceType,
      String[] stringElements, Image[] imageElements);

  // Methods
  public int append(String stringPart, Image imagePart);
  public void delete(int elementNum);
  public void deleteAll();
  public int getFitPolicy();
  public Font getFont(int elementNum);
  public Image getImage(int elementNum);
  public int getSelectedFlags(boolean[] selectedArray_return);
  public int getSelectedIndex();
  public String getString(int elementNum);
  public void insert(int elementNum, String stringPart, Image imagePart);
  public boolean isSelected(int elementNum);
  public void set(int elementNum, String stringPart, Image imagePart);
  public void setFitPolicy(int fitPolicy);
  public void setFont(int elementNum, Font font);
  public void setSelectedFlags(boolean[] selectedArray);
  public void setSelectedIndex(int elementNum, boolean selected);
  public int size();
}
```

Class javax.microedition.lcdui.Command

```
public class Command
    extends java.lang.Object {
  // Constants
  public static final int BACK;
  public static final int CANCEL;
  public static final int EXIT;
  public static final int HELP;
  public static final int ITEM;
  public static final int OK;
  public static final int SCREEN;
  public static final int STOP;

  // Constructors
  public Command(String label, int commandType, int priority);
  public Command(String shortLabel, String longLabel,
      int commandType, int priority);

  // Methods
  public int getCommandType();
  public String getLabel();
  public String getLongLabel();
  public int getPriority();
}
```

Interface javax.microedition.lcdui.CommandListener

```
public interface CommandListener {
  // Methods
  public void commandAction(Command c, Displayable d);
}
```

Class javax.microedition.lcdui.CustomItem

```
public abstract class CustomItem
      extends javax.microedition.lcdui.Item {
    // Constants
   protected static final int KEY_PRESS;
   protected static final int KEY_RELEASE;
   protected static final int KEY_REPEAT;
   protected static final int NONE;
   protected static final int POINTER_DRAG;
   protected static final int POINTER_PRESS;
   protected static final int POINTER_RELEASE;
   protected static final int TRAVERSE_HORIZONTAL;
   protected static final int TRAVERSE_VERTICAL;
```

```
  // Constructors
 protected CustomItem(String label);

  // Methods
 public int getGameAction(int keyCode);
 protected final int getInteractionModes();
 protected abstract int getMinContentHeight();
 protected abstract int getMinContentWidth();
 protected abstract int getPrefContentHeight(int width);
 protected abstract int getPrefContentWidth(int height);
 protected void hideNotify();
 protected final void invalidate();
 protected void keyPressed(int keyCode);
 protected void keyReleased(int keyCode);
 protected void keyRepeated(int keyCode);
 protected abstract void paint(Graphics g, int w, int h);
 protected void pointerDragged(int x, int y);
 protected void pointerPressed(int x, int y);
 protected void pointerReleased(int x, int y);
 protected final void repaint();
 protected final void repaint(int x, int y, int w, int h);
 protected void showNotify();
 protected void sizeChanged(int w, int h);
 protected boolean traverse(int dir, int viewportWidth, int viewportHeight,
      int[] visRect_inout);
 protected void traverseOut();
}
```

Class javax.microedition.lcdui.DateField

```
public class DateField
    extends javax.microedition.lcdui.Item {
  // Constants
  public static final int DATE;
  public static final int DATE_TIME;
  public static final int TIME;

  // Constructors
  public DateField(String label, int mode);
  public DateField(String label, int mode, TimeZone timeZone);

  // Methods
  public Date getDate();
  public int getInputMode();
  public void setDate(Date date);
  public void setInputMode(int mode);
}
```

Class javax.microedition.lcdui.Display

```
public class Display
    extends java.lang.Object {
  // Constants
 public static final int ALERT;
 public static final int CHOICE_GROUP_ELEMENT;
 public static final int COLOR_BACKGROUND;
 public static final int COLOR_BORDER;
 public static final int COLOR_FOREGROUND;
 public static final int COLOR_HIGHLIGHTED_BACKGROUND;
 public static final int COLOR_HIGHLIGHTED_BORDER;
 public static final int COLOR_HIGHLIGHTED_FOREGROUND;
 public static final int LIST_ELEMENT;

  // Static methods
 public static Display getDisplay(MIDlet m);

  // Methods
 public void callSerially(Runnable r);
 public boolean flashBacklight(int duration);
 public int getBestImageHeight(int imageType);
 public int getBestImageWidth(int imageType);
 public int getBorderStyle(boolean highlighted);
 public int getColor(int colorSpecifier);
 public Displayable getCurrent();
 public boolean isColor();
 public int numAlphaLevels();
 public int numColors();
 public void setCurrent(Displayable nextDisplayable);
 public void setCurrent(Alert alert, Displayable nextDisplayable);
 public void setCurrentItem(Item item);
 public boolean vibrate(int duration);
}
```

Class javax.microedition.lcdui.Displayable

```
public abstract class Displayable
    extends java.lang.Object {
  // Methods
  public void addCommand(Command cmd);
  public int getHeight();
  public Ticker getTicker();
  public String getTitle();
  public int getWidth();
  public boolean isShown();
  public void removeCommand(Command cmd);
```

```
  public void setCommandListener(CommandListener l);
  public void setTicker(Ticker ticker);
  public void setTitle(String s);
  protected void sizeChanged(int w, int h);
}
```

Class javax.microedition.lcdui.Font

```
public final class Font
    extends java.lang.Object {
  // Constants
  public static final int FACE_MONOSPACE;
  public static final int FACE_PROPORTIONAL;
  public static final int FACE_SYSTEM;
  public static final int FONT_INPUT_TEXT;
  public static final int FONT_STATIC_TEXT;
  public static final int SIZE_LARGE;
  public static final int SIZE_MEDIUM;
  public static final int SIZE_SMALL;
  public static final int STYLE_BOLD;
  public static final int STYLE_ITALIC;
  public static final int STYLE_PLAIN;
  public static final int STYLE_UNDERLINED;

  // Static methods
  public static Font getDefaultFont();
 public static Font getFont(int fontSpecifier);
  public static Font getFont(int face, int style, int size);

  // Methods
  public native int charWidth(char ch);
  public native int charsWidth(char[] ch, int offset, int length);
  public int getBaselinePosition();
  public int getFace();
  public int getHeight();
  public int getSize();
  public int getStyle();
  public boolean isBold();
  public boolean isItalic();
  public boolean isPlain();
  public boolean isUnderlined();
  public native int stringWidth(String str);
  public native int substringWidth(String str, int offset, int len);
}
```

Class javax.microedition.lcdui.Form

```
public class Form
    extends javax.microedition.lcdui.Screen {
  // Constructors
  public Form(String title);
  public Form(String title, Item[] items);

  // Methods
  public int append(Item item);
  public int append(String str);
  public int append(Image img);
  public void delete(int itemNum);
  public void deleteAll();
  public Item get(int itemNum);
  public int getHeight();
  public int getWidth();
  public void insert(int itemNum, Item item);
  public void set(int itemNum, Item item);
  public void setItemStateListener(ItemStateListener iListener);
  public int size();
}
```

Class javax.microedition.lcdui.Gauge

```
public class Gauge
    extends javax.microedition.lcdui.Item {
  // Constants
 public static final int CONTINUOUS_IDLE;
 public static final int CONTINUOUS_RUNNING;
 public static final int INCREMENTAL_IDLE;
 public static final int INCREMENTAL_UPDATING;
 public static final int INDEFINITE;

  // Constructors
 public Gauge(String label, boolean interactive, int maxValue,
      int initialValue);

  // Methods
 public void addCommand(Command cmd);
 public int getMaxValue();
 public int getValue();
 public boolean isInteractive();
 public void setDefaultCommand(Command cmd);
 public void setItemCommandListener(ItemCommandListener l);
 public void setLabel(String label);
 public void setLayout(int layout);
 public void setMaxValue(int maxValue);
```

```
 public void setPreferredSize(int width, int height);
 public void setValue(int value);
}
```

Class javax.microedition.lcdui.Graphics

```
public class Graphics
    extends java.lang.Object {
  // Constants
  public static final int BASELINE;
  public static final int BOTTOM;
  public static final int DOTTED;
  public static final int HCENTER;
  public static final int LEFT;
  public static final int RIGHT;
  public static final int SOLID;
  public static final int TOP;
  public static final int VCENTER;

  // Methods
  public void clipRect(int x, int y, int width, int height);
  public void copyArea(int x_src, int y_src, int width, int height,
      int x_dest, int y_dest, int anchor);
  public native void drawArc(int x, int y, int width, int height,
      int startAngle, int arcAngle);
  public native void drawChar(char character, int x, int y, int anchor);
  public native void drawChars(char[] data, int offset, int length,
      int x, int y, int anchor);
  public native void drawImage(Image img, int x, int y, int anchor);
  public native void drawLine(int x1, int y1, int x2, int y2);
  public native void drawRGB(int[] rgbData, int offset, int scanlength,
      int x, int y, int width, int height, boolean processAlpha);
  public native void drawRect(int x, int y, int width, int height);
  public native void drawRegion(Image src,
      int x_src, int y_src, int width, int height, int transform,
      int x_dest, int y_dest, int anchor);
  public native void drawRoundRect(int x, int y, int width, int height,
      int arcWidth, int arcHeight);
  public native void drawString(String str, int x, int y, int anchor);
  public native void drawSubstring(String str, int offset, int len,
      int x, int y, int anchor);
  public native void fillArc(int x, int y, int width, int height,
      int startAngle, int arcAngle);
  public native void fillRect(int x, int y, int width, int height);
  public native void fillRoundRect(int x, int y, int width, int height,
      int arcWidth, int arcHeight);
  public native void fillTriangle(int x1, int y1, int x2, int y2,
      int x3, int y3);
```

```
  public int getBlueComponent();
  public int getClipHeight();
  public int getClipWidth();
  public int getClipX();
  public int getClipY();
  public int getColor();
  public native int getDisplayColor(int color);
  public Font getFont();
  public int getGrayScale();
  public int getGreenComponent();
  public int getRedComponent();
  public int getStrokeStyle();
  public int getTranslateX();
  public int getTranslateY();
  public void setClip(int x, int y, int width, int height);
  public void setColor(int red, int green, int blue);
  public void setColor(int RGB);
  public void setFont(Font font);
  public void setGrayScale(int value);
  public void setStrokeStyle(int style);
  public void translate(int x, int y);
}
```

Class javax.microedition.lcdui.Image

```
public class Image
    extends java.lang.Object {
  // Static methods
  public static Image createImage(int width, int height);
  public static Image createImage(Image source);
  public static Image createImage(String name);
  public static Image createImage(byte[] imageData, int imageOffset,
      int imageLength);
  public static Image createImage(Image image, int x, int y,
      int width, int height, int transform);
  public static Image createImage(InputStream stream);
  public static Image createRGBImage(int[] rgb,
      int width, int height, boolean processAlpha);

  // Methods
  public Graphics getGraphics();
  public int getHeight();
  public native void getRGB(int[] rgbData, int offset, int scanlength,
      int x, int y, int width, int height);
  public int getWidth();
  public boolean isMutable();
}
```

Class javax.microedition.lcdui.ImageItem

```
public class ImageItem
    extends javax.microedition.lcdui.Item {
  // Constants
  public static final int LAYOUT_CENTER;
  public static final int LAYOUT_DEFAULT;
  public static final int LAYOUT_LEFT;
  public static final int LAYOUT_NEWLINE_AFTER;
  public static final int LAYOUT_NEWLINE_BEFORE;
  public static final int LAYOUT_RIGHT;

  // Constructors
  public ImageItem(String label, Image img, int layout, String altText);
  public ImageItem(String label, Image image, int layout, String altText,
      int appearanceMode);

  // Methods
  public String getAltText();
  public int getAppearanceMode();
  public Image getImage();
  public int getLayout();
  public void setAltText(String text);
  public void setImage(Image img);
  public void setLayout(int layout);
}
```

Class javax.microedition.lcdui.Item

```
public abstract class Item
    extends java.lang.Object {
  // Constants
 public static final int BUTTON;
 public static final int HYPERLINK;
 public static final int LAYOUT_2;
 public static final int LAYOUT_BOTTOM;
 public static final int LAYOUT_CENTER;
 public static final int LAYOUT_DEFAULT;
 public static final int LAYOUT_EXPAND;
 public static final int LAYOUT_LEFT;
 public static final int LAYOUT_NEWLINE_AFTER;
 public static final int LAYOUT_NEWLINE_BEFORE;
 public static final int LAYOUT_RIGHT;
 public static final int LAYOUT_SHRINK;
 public static final int LAYOUT_TOP;
 public static final int LAYOUT_VCENTER;
```

```
 public static final int LAYOUT_VEXPAND;
 public static final int LAYOUT_VSHRINK;
 public static final int PLAIN;

  // Methods
 public void addCommand(Command cmd);
 public String getLabel();
 public int getLayout();
 public int getMinimumHeight();
 public int getMinimumWidth();
 public int getPreferredHeight();
 public int getPreferredWidth();
 public void notifyStateChanged();
 public void removeCommand(Command cmd);
 public void setDefaultCommand(Command cmd);
 public void setItemCommandListener(ItemCommandListener l);
 public void setLabel(String label);
 public void setLayout(int layout);
 public void setPreferredSize(int width, int height);
}
```

Interface javax.microedition.lcdui.ItemCommandListener

```
public interface ItemCommandListener {
   // Methods
  public void commandAction(Command c, Item item);
 }
```

Interface javax.microedition.lcdui.ItemStateListener

```
public interface ItemStateListener {
  // Methods
  public void itemStateChanged(Item item);
}
```

Class javax.microedition.lcdui.List

```
public class List
    extends javax.microedition.lcdui.Screen
    implements Choice {
  // Constants
  public static final Command SELECT_COMMAND;

  // Constructors
  public List(String title, int listType);
  public List(String title, int listType, String[] stringElements,
      Image[] imageElements);
```

```
    // Methods
    public int append(String stringPart, Image imagePart);
    public void delete(int elementNum);
    public void deleteAll();
    public int getFitPolicy();
    public Font getFont(int elementNum);
    public Image getImage(int elementNum);
    public int getSelectedFlags(boolean[] selectedArray_return);
    public int getSelectedIndex();
    public String getString(int elementNum);
    public void insert(int elementNum, String stringPart, Image imagePart);
    public boolean isSelected(int elementNum);
    public void removeCommand(Command cmd);
    public void set(int elementNum, String stringPart, Image imagePart);
    public void setFitPolicy(int fitPolicy);
    public void setFont(int elementNum, Font font);
    public void setSelectCommand(Command command);
    public void setSelectedFlags(boolean[] selectedArray);
    public void setSelectedIndex(int elementNum, boolean selected);
    public void setTicker(Ticker ticker);
    public void setTitle(String s);
    public int size();
  }
```

Class javax.microedition.lcdui.Screen

```
  public abstract class Screen
      extends javax.microedition.lcdui.Displayable {
    // Methods
  }
```

Class javax.microedition.lcdui.Spacer

```
 public class Spacer
      extends javax.microedition.lcdui.Item {
    // Constructors
   public Spacer(int minWidth, int minHeight);

    // Methods
   public void addCommand(Command cmd);
   public void setDefaultCommand(Command cmd);
   public void setLabel(String label);
   public void setMinimumSize(int minWidth, int minHeight);
  }
```

Class javax.microedition.lcdui.StringItem

```
public class StringItem
    extends javax.microedition.lcdui.Item {
  // Constructors
  public StringItem(String label, String text);
  public StringItem(String label, String text, int appearanceMode);

  // Methods
  public int getAppearanceMode();
  public Font getFont();
  public String getText();
  public void setFont(Font font);
  public void setPreferredSize(int width, int height);
  public void setText(String text);
}
```

Class javax.microedition.lcdui.TextBox

```
public class TextBox
    extends javax.microedition.lcdui.Screen {
  // Constructors
  public TextBox(String title, String text, int maxSize, int constraints);

  // Methods
  public void delete(int offset, int length);
  public int getCaretPosition();
  public int getChars(char[] data);
  public int getConstraints();
  public int getMaxSize();
  public String getString();
  public void insert(String src, int position);
  public void insert(char[] data, int offset, int length, int position);
  public void setChars(char[] data, int offset, int length);
  public void setConstraints(int constraints);
  public void setInitialInputMode(String characterSubset);
  public int setMaxSize(int maxSize);
  public void setString(String text);
  public void setTicker(Ticker ticker);
  public void setTitle(String s);
  public int size();
}
```

Class javax.microedition.lcdui.TextField

```
public class TextField
    extends javax.microedition.lcdui.Item {
  // Constants
  public static final int ANY;
  public static final int CONSTRAINT_MASK;
  public static final int DECIMAL;
  public static final int EMAILADDR;
  public static final int INITIAL_CAPS_SENTENCE;
  public static final int INITIAL_CAPS_WORD;
  public static final int NON_PREDICTIVE;
  public static final int NUMERIC;
  public static final int PASSWORD;
  public static final int PHONENUMBER;
  public static final int SENSITIVE;
  public static final int UNEDITABLE;
  public static final int URL;

  // Constructors
  public TextField(String label, String text, int maxSize, int constraints);

  // Methods
  public void delete(int offset, int length);
  public int getCaretPosition();
  public int getChars(char[] data);
  public int getConstraints();
  public int getMaxSize();
  public String getString();
  public void insert(String src, int position);
  public void insert(char[] data, int offset, int length, int position);
  public void setChars(char[] data, int offset, int length);
  public void setConstraints(int constraints);
  public void setInitialInputMode(String characterSubset);
  public int setMaxSize(int maxSize);
  public void setString(String text);
  public int size();
}
```

Class javax.microedition.lcdui.Ticker

```
public class Ticker
    extends java.lang.Object {
  // Constructors
  public Ticker(String str);
```

```
    // Methods
    public String getString();
    public void setString(String str);
  }
```

Package javax.microedition.lcdui.game

Class javax.microedition.lcdui.game.GameCanvas

```
public abstract class GameCanvas
     extends javax.microedition.lcdui.Canvas {
    // Constants
   public static final int DOWN_PRESSED;
   public static final int FIRE_PRESSED;
   public static final int GAME_A_PRESSED;
   public static final int GAME_B_PRESSED;
   public static final int GAME_C_PRESSED;
   public static final int GAME_D_PRESSED;
   public static final int LEFT_PRESSED;
   public static final int RIGHT_PRESSED;
   public static final int UP_PRESSED;

    // Constructors
   protected GameCanvas(boolean suppressKeyEvents);

    // Methods
   public void flushGraphics(int x, int y, int width, int height);
   public void flushGraphics();
   protected Graphics getGraphics();
   public int getKeyStates();
   public void paint(Graphics g);
  }
```

Class javax.microedition.lcdui.game.Layer

```
public abstract class Layer
     extends java.lang.Object {
    // Methods
   public final int getHeight();
   public final int getWidth();
   public final int getX();
   public final int getY();
   public final boolean isVisible();
   public void move(int dx, int dy);
```

```
  public abstract void paint(Graphics g);
  public void setPosition(int x, int y);
  public void setVisible(boolean visible);
 }
```

Class javax.microedition.lcdui.game.LayerManager

```
public class LayerManager
      extends java.lang.Object {
    // Constructors
  public LayerManager();

    // Methods
  public void append(Layer l);
  public Layer getLayerAt(int index);
  public int getSize();
  public void insert(Layer l, int index);
  public void paint(Graphics g, int x, int y);
  public void remove(Layer l);
  public void setViewWindow(int x, int y, int width, int height);
 }
```

Class javax.microedition.lcdui.game.Sprite

```
public class Sprite
     extends javax.microedition.lcdui.game.Layer {
   // Constants
  public static final int TRANS_MIRROR;
  public static final int TRANS_MIRROR_ROT180;
  public static final int TRANS_MIRROR_ROT270;
  public static final int TRANS_MIRROR_ROT90;
  public static final int TRANS_NONE;
  public static final int TRANS_ROT180;
  public static final int TRANS_ROT270;
  public static final int TRANS_ROT90;

   // Constructors
  public Sprite(Image image);
  public Sprite(Image image, int frameWidth, int frameHeight);
  public Sprite(Sprite s);
```

```
  // Methods
 public final boolean collidesWith(Sprite s, boolean pixelLevel);
 public final boolean collidesWith(TiledLayer t, boolean pixelLevel);
 public final boolean collidesWith(Image image, int x, int y,
      boolean pixelLevel);
 public void defineCollisionRectangle(int x, int y, int width, int height);
 public void defineReferencePixel(int x, int y);
 public final int getFrame();
 public int getFrameSequenceLength();
 public int getRawFrameCount();
 public int getRefPixelX();
 public int getRefPixelY();
 public void nextFrame();
 public final void paint(Graphics g);
 public void prevFrame();
 public void setFrame(int sequenceIndex);
 public void setFrameSequence(int[] sequence);
 public void setImage(Image img, int frameWidth, int frameHeight);
 public void setRefPixelPosition(int x, int y);
 public void setTransform(int transform);
}
```

Class javax.microedition.lcdui.game.TiledLayer

```
public class TiledLayer
     extends javax.microedition.lcdui.game.Layer {
   // Constructors
  public TiledLayer(int columns, int rows, Image image,
       int tileWidth, int tileHeight);

   // Methods
  public int createAnimatedTile(int staticTileIndex);
  public void fillCells(int col, int row, int numCols, int numRows,
       int tileIndex);
  public int getAnimatedTile(int animatedTileIndex);
  public int getCell(int col, int row);
  public final int getCellHeight();
  public final int getCellWidth();
  public final int getColumns();
  public final int getRows();
  public final void paint(Graphics g);
  public void setAnimatedTile(int animatedTileIndex, int staticTileIndex);
  public void setCell(int col, int row, int tileIndex);
  public void setStaticTileSet(Image image, int tileWidth, int tileHeight);
 }
```

Package javax.microedition.media

Interface javax.microedition.media.Control

```
public interface Control {
  }
```

Interface javax.microedition.media.Controllable

```
 public interface Controllable {
    // Methods
   public Control getControl(String controlType);
   public Control[] getControls();
  }
```

Class javax.microedition.media.Manager

```
public final class Manager
      extends java.lang.Object {
    // Constants
   public static final String TONE_DEVICE_LOCATOR;

    // Static methods
   public static Player createPlayer(String locator);
   public static Player createPlayer(InputStream stream, String type);
   public static String getSupportedContentTypes(String protocol);
   public static String getSupportedProtocols(String content_type);
   public static void playTone(int note, int duration, int volume);
  }
```

Interface javax.microedition.media.Player

```
 public interface Player
      implements Controllable {
    // Constants
   public static final int CLOSED;
   public static final int PREFETCHED;
   public static final int REALIZED;
   public static final int STARTED;
   public static final long TIME_UNKNOWN;
   public static final int UNREALIZED;
```

```
  // Methods
 public void addPlayerListener(PlayerListener playerListener);
 public void close();
 public void deallocate();
 public String getContentType();
 public long getDuration();
 public long getMediaTime();
 public int getState();
 public void prefetch();
 public void realize();
 public void removePlayerListener(PlayerListener playerListener);
 public void setLoopCount(int count);
 public long setMediaTime(long now);
 public void start();
 public void stop();
}
```

Interface javax.microedition.media.PlayerListener

```
public interface PlayerListener {
   // Constants
  public static final String CLOSED;
  public static final String DEVICE_AVAILABLE;
  public static final String DEVICE_UNAVAILABLE;
  public static final String DURATION_UPDATED;
  public static final String END_OF_MEDIA;
  public static final String ERROR;
  public static final String STARTED;
  public static final String STOPPED;
  public static final String VOLUME_CHANGED;

   // Methods
  public void playerUpdate(Player player, String event, Object eventData);
 }
```

Package javax.microedition.media.control

Interface javax.microedition.media.control.ToneControl

```
public interface ToneControl
     implements Control {
   // Constants
  public static final byte BLOCK_END;
  public static final byte BLOCK_START;
  public static final byte C4;
  public static final byte PLAY_BLOCK;
```

```
  public static final byte REPEAT;
  public static final byte RESOLUTION;
  public static final byte SET_VOLUME;
  public static final byte SILENCE;
  public static final byte TEMPO;
  public static final byte VERSION;

   // Methods
  public void setSequence(byte[] sequence);
 }
```

Interface javax.microedition.media.control.VolumeControl

```
public interface VolumeControl
     implements Control {
   // Methods
  public int getLevel();
  public boolean isMuted();
  public int setLevel(int level);
  public void setMute(boolean mute);
 }
```

Package javax.microedition.midlet

Class javax.microedition.midlet.MIDlet

```
public abstract class MIDlet
    extends java.lang.Object {
  // Constructors
  protected MIDlet();

  // Methods
  public final int checkPermission(String permission);
  protected abstract void destroyApp(boolean unconditional);
  public final String getAppProperty(String key);
  public final void notifyDestroyed();
  public final void notifyPaused();
  protected abstract void pauseApp();
  public final boolean platformRequest(String URL);
  public final void resumeRequest();
  protected abstract void startApp();
}
```

Package javax.microedition.pki

```
public interface Certificate {
   // Methods
  public String getIssuer();
  public long getNotAfter();
  public long getNotBefore();
  public String getSerialNumber();
  public String getSigAlgName();
  public String getSubject();
  public String getType();
  public String getVersion();
 }
```

Package javax.microedition.rms

Interface javax.microedition.rms.RecordComparator

```
public interface RecordComparator {
  // Constants
  public static final int EQUIVALENT;
  public static final int FOLLOWS;
  public static final int PRECEDES;

  // Methods
  public int compare(byte[] rec1, byte[] rec2);
}
```

Interface javax.microedition.rms.RecordEnumeration

```
public interface RecordEnumeration {
  // Methods
  public void destroy();
  public boolean hasNextElement();
  public boolean hasPreviousElement();
  public boolean isKeptUpdated();
  public void keepUpdated(boolean keepUpdated);
  public byte[] nextRecord();
  public int nextRecordId();
  public int numRecords();
  public byte[] previousRecord();
  public int previousRecordId();
  public void rebuild();
  public void reset();
}
```

Interface javax.microedition.rms.RecordFilter

```
public interface RecordFilter {
  // Methods
  public boolean matches(byte[] candidate);
}
```

Interface javax.microedition.rms.RecordListener

```
public interface RecordListener {
  // Methods
  public void recordAdded(RecordStore recordStore, int recordId);
  public void recordChanged(RecordStore recordStore, int recordId);
  public void recordDeleted(RecordStore recordStore, int recordId);
}
```

Class javax.microedition.rms.RecordStore

```
public class RecordStore
    extends java.lang.Object {
  // Constants
public static final int AUTHMODE_ANY;
public static final int AUTHMODE_PRIVATE;

  // Static methods
  public static void deleteRecordStore(String recordStoreName);
  public static String listRecordStores();
  public static RecordStore openRecordStore(String recordStoreName,
      boolean createIfNecessary);
  public static RecordStore openRecordStore(String recordStoreName,
      boolean createIfNecessary, int authmode, boolean writable);
  public static RecordStore openRecordStore(String recordStoreName,
      String vendorName, String suiteName);


  // Methods
  public int addRecord(byte[] data, int offset, int numBytes);
  public void addRecordListener(RecordListener listener);
  public void closeRecordStore();
  public void deleteRecord(int recordId);
  public RecordEnumeration enumerateRecords(RecordFilter filter,
      RecordComparator comparator, boolean keepUpdated);
  public long getLastModified();
  public String getName();
  public int getNextRecordID();
  public int getNumRecords();
  public int getRecord(int recordId, byte[] buffer, int offset);
```

```
  public byte[] getRecord(int recordId);
  public int getRecordSize(int recordId);
  public int getSize();
  public int getSizeAvailable();
  public int getVersion();
  public void removeRecordListener(RecordListener listener);
  public void setMode(int authmode, boolean writable);
  public void setRecord(int recordId, byte[] newData, int offset,
      int numBytes);
}
```

INDEX

Numbers and Symbols

* (asterisk) wildcard character
  used with filter for list() method, 122
/ (forward slash)
  in a directory name, 123
  used at end of directory names, 122
| (pipe character) separator
  for storing a key and value pair in a record, 110
1-bit color
  defined, 236
3D corner piece
  rotating, 291–297
3D graphics
  combining vertex information into a VertexBuffer, 285–286
  defining normals, 285
  getting started with, 277–296
  modifying a TriangleCanvas to rotate a square, 290–291
  rendering a single frame of, 276–277
  rotating a 3D corner piece, 291–297
3D graphics API
  overview of, 275–277
3D triangle vector
  code for changing, 280
3D Studio Max, Version 7
  capability to export .m3g files, 298
3D World
  method for obtaining, 302
3D World .m3g file
  method for loading active Camera, 302
  method for obtaining Background, 302

A

ABB. *See* Audio Building Block (ABB)
abstraction
  using to create applications, 53
add<data type>() method
  for setting Contact field values, 136–137
addCommand() method
  for adding commands to an Alert, 64
  using to manage Item commands, 76
addContact() method
  for adding a contact to a PIM list, 140
addRecord() method
  for adding a new record to a record store, 107
addresses
  managing for multipart messages, 182–183
alerts
  adding commands to, 64
  creating a simple timed, 64
  types of, 63
  using, 63–66
anchor points
  example for images, 244
  using to draw text in Graphics class, 237–239
animate() method
  calling to animate the hopping kangaroo, 302–303
animated cell
  changing contents of, 263
animated tiles
  creating and using, 262–263
animation
  code example of typical, 251
  driving with GameCanvas, 255–257
  and multithreading, 250–254
Ant
  for automating MIDlet suite builds, 25–27
appearance modes
  for controlling appearance of StringItem and ImageItem, 79
append() method
  for adding elements to lists, 70
application deployment
  optimizing, 340–341

application descriptor file
creating, 24
function of, 34
in MIDlet suite, 31
application manager
for controlling MIDlet installation, execution, and life cycle, 29–30
applications
coding for speed, 337–340
data security needs for when using the Internet, 344
importance of including only classes you need, 341
importance of releasing resources to free memory, 338–340
partitioning for optimization, 340–341
testing speed of, 332
using arrays instead of objects for speed optimizations, 338
using buffered I/O for speed optimizations, 338
using loops for speed optimizations, 337
ways of creating to work on all devices, 53
application-specific attribute
putting in application descriptor, 34
Applied Cryptography: Protocols, Algorithms, and Source Code in C (John Wiley & Sons, 1995)
by Bruce Schneier, 344
arraycopy() method
function of, 45
arrays
using instead of objects for speed optimizations, 337–338
assymmetric cipher, 344
asterisk (*) wildcard character. *See* * (asterisk) wildcard character
attributes
adding to field values, 136
Audio Building Block (ABB)
implementation of, 305
supported content types and protocols, 312–314
audio data
common content types, 311–312
audio data path
example, 312
audio files
ABB support for playing, 308–311
code for playing over the Internet, 311
AudioMIDlet-URL property
setting to play audio files over the Internet, 311
authentication
as part of data security, 344
AUTHMODE_ANY
changing authorization mode to, 105
authorization mode
default for record stores, 105–106
Autodesk's 3D Studio Max, Version 7
capability to export .m3g files, 298
availableSize() method
finding available space on a file system with, 121

B

Background
methods of, 287
Background object
methods to set color or image, 287
benchmarking
in the J2ME world, 331–332
BinaryMessage
setting payload of, 160
blanket permissions, 36
blitting
for copying a region of the screen to another location, 246
blocking receive() method
calling, 171
for receiving SMS messages, 170–171
Bluetooth
accessing the local stack, 199–200
creating a service, 206–207
creating PANs with, 195–229
example of an implementation, 197
function of getFriendlyName() method, 200
network definition, 197
networking with devices near you, 196–197
and OBEX (Object Exchange protocol), 195–229
using UUID to discover a service, 203–204
Bluetooth API. *See* Java API for Bluetooth

Bluetooth "Assigned Numbers" document
for list of ServiceRecord attributes, 206
website address for, 201
Bluetooth, CLDC, and MIDP, 195–196
Bluetooth client
coding, 209–211
Bluetooth Control Center (BCC)
function of, 205
Bluetooth dating client
DateClient.java code for, 210–211
Bluetooth dating service
coding, 211–215
creating, 207–215
running on WTK emulators, 209
Bluetooth devices
properties that must be available on, 200
typical interactions between, 198–199
Bluetooth manager
obtaining the singleton instance of, 200
Bluetooth network
piconet as, 195–196
Bluetooth Serial Port Profile, 206
Bluetooth service
creating, 206–207
Bluetooth service model
showing device interactions, 198
Borland JBuilder X Mobile Edition
website address, 12
Bouncy Castle ciphers
using, 358
Bouncy Castle cryptography package
open-source toolbox for cryptographic algorithms, 345–346
trimming down to size, 364–366
using, 347
BT2 project
MIDlet properties for, 208
BTMIDlet project
for creating a Bluetooth dating service, 207–215
setting dating preferences, 208
BTMIDlet.java file
for Bluetooth dating service, 212–215
buffered I/O
using for speed optimizations, 338
Building Blocks
concept of, 6
BUTTON appearance mode, 79
bytecode obfuscator
for reducing size of MIDlet suite JAR, 341
using, 24–25
bytecode verification
for preverifying class files, 17

C

calendars
in CLDC/MIDP, 52
in J2SE classes, 51
callSerially() method
of Display, 233
for executing your code in a user-interface thread, 251
Camera class
in M3G, 287–288
camera phone
snapping pictures on, 325–329
CameraMIDlet
code for, 327–329
Canvas
code for a typical implementation, 232
code for showing it in action, 241–242
coordinate axes, 233
coordinate space, 233
example showing how to place text on, 238
vs. GameCanvas, 255
key events, 246–247
methods for finding the size of, 231–232
placing text on, 238
video on custom, 322
Canvas class
as heart of MIDP's custom user-interface API, 231
information about, 231–232
for specialized interfaces, 61
Canvas object
calling serviceRepaints() on, 233
"capture://video" URL
for accessing camera phone as a player, 326
card insertion and removal
listening for, 123–131
CBS. *See* Cell Broadcast Service (CBS)
CBS messages. *See* Cell Broadcast Service (CBS)
CDC. *See* connected device configuration
CDMA
support for SMS, 165
CDMA2000-1X
support for SMS, 165

CDMA2000-MX
  support for SMS, 165
Cell Broadcast Service (CBS)
  receiving messages, 173–181
  using WMA to process and receive, 165
cells
  in tiled layers, 260–261
central registry class
  for managing listeners, 123
character encodings
  in MIDP, 48
ChoiceGroup class
  constructors featured in, 86
  MULTIPLE type for, 86
choiceType
  constants defined, 86
cipher modes
  Java Cryptography for more information about, 358
ciphers
  as cryptographic solution for data security, 344
ciphertext
  conversion of plaintext to for data security, 344
class files
  CLDC two-step bytecode verification, 17
  preverifying, 17
classes
  included in java.util package, 49–50
  java.io in J2SE SDK 1.4.2 and CLDC 1.0 and 1.1, 46
classloaders
  lack of support for in CLDC, 42
ClassNotFoundException, 30
CLDC (connected limited device configuration)
  lack of support for defining classloaders in, 42
  lack of support for native methods in, 42
  lack of support for Reflection API in, 42
  multithreading in, 42
  relationship between Java API for Bluetooth, MIDP and, 196
CLDC 1.0
  java.io classes in, 46
  java.io interfaces in, 45–46, 47
  java.lang package classes and interfaces, 40–41
  java.lang.ref package classes, 41
  new variables and methods in, 43–44
  lack of floating-point support in, 39
  relationship between File Connection Optional Package and, 118
CLDC 1.1
  java.io classes in, 46
  java.io interfaces in, 45–46, 47
  java.lang package classes and interfaces, 40–41
  java.lang.ref package classes, 41
  relationship between File Connection Optional Package and, 118
  thread naming support in, 42
CLDC classes
  vs. J2SE classes, 48
CLDC home page
  website address, 5
CLDC/MIDP classes
  for specifying dates and times, 52
client authentication
  TLS lack of, 345
clipping shape
  methods for setting, 246
CLOSED state
  for Players, 315
closeRecordStore() method
  calling to close a record store, 104–105
code example
  for accessing a resource file, 116
  for accessing a shared record store, 106
  for accessing binary message content, 171
  for accessing MessagePart header information, 185
  for accessing other headers, 184
  for accessing parts of a multipart message, 184
  for accessing text message content, 171
  for adding a new record to a record store, 107
  for adding a MessageListener on the MessageConnection, 172
  for adding and removing file system listeners, 123
  for adding an item in the middle of a form, 74
  for adding an Item to a form, 74
  for adding a ticker to a screen, 61
  for adding new categories to PIM lists, 132

for adding or removing commands, 57
for adding Texture2D to Appearance, 297
for adding texture coordinates to VertexBuffer, 297
for adjusting Sprites reference pixel, 265
for adjusting the position of a layer, 259
for Ant target that runs ProGuard, 365
for applying a transformation to a Sprite, 264
for assigning a tile to a cell, 261
for assigning a tile to a range of tiles, 262
for Bluetooth dating client-DateClient.java, 210–211
for Bluetooth dating service-BTMIDlet.java, 212–215
for building a TriangleStripArray for CornerCanvas, 297
for calculating method execution time, 332
for calling the removeContact() method, 137
for capturing Images with your camera phone, 327–329
for changing a 3D triangle vector, 280
for changing authorization mode and writable flag of open record store, 105
for changing current frame sequence for a Sprite, 264
for changing file or file system read or write attribute, 120
for changing Sprite source image, 263
for changing the contents of an animated cell, 263
for checking bytes in a record store, 106
for checking for list of supported fields, 135
checking if a connection is associated with a directory, 120
for confirming nonexistence of a file, 121
for constraining input to an e-mail address, 62
for constructing an HTTPS connection string, 158
of a constructor for Image3D, 295
constructors for creating a new MessagePart, 185
for controlling hidden attribute of a file or file system, 120
for converting a byte array to an Image, 326
converting between byte arrays and hex encoded strings, 352
converting key code to game action and displaying on screen, 248
for creating a client mode connection, 167
for creating a command specific to an application, 57
for creating a Form, 73
for creating a Form with two items, 87–88
for creating a mutable Image, 70
creating an application descriptor file, 24
for creating and initializing a TiledLayer, 262
for creating and using animated tiles, 262–263
for creating a new Contact with Contact.NAME field, 136–137
creating a new Sprite and setting its frame sequence, 264
for creating an Image from another Image, 70
for creating an immutable Image, 70
creating an interactive Gauge, 83
for creating a server mode connection, 168
for creating a SHA-1 message digest object, 347
for creating a shared record store, 105
for creating a simple timed Alert, 64
for creating a small, italic, proportional font, 240
for creating a TextBox, 62
for creating a TextField, 80
for creating a TiledLayer, 261–262
for creating a timestamp and random number, 349
for creating a verbuf VertexBuffer, 286
for creating commands with short or long labels, 57
for creating Sprites, 263
for creating standard OK command, 57
creating the Jargoneer MIDlet TextBox, 21
for creating the vertexArray in CornerCanvas, 295
for defining a submesh with a TriangleStripArray, 286
for defining normals, 285
deleting a message part from a multipart message, 184
for deleting and replacing records, 108
for deleting categories from PIM lists, 132
for deleting files and directories, 122
demonstrating some simple drawing and filling, 234

demonstrating the creation and use of fonts, 240–241
for detecting collisions with other Sprites, TiledLayers, and Images, 266
to determine if a file or directory is hidden, 120
for determining if a file can be read, 120
for determining if a file can be written to, 120
for disabling culling, 289
for discovering a list of nearby devices, 202
for discovering devices or services in a PAN, 201
for discovering services, 202
for displaying names in the PIM database, 140–142
for drawing a box around a string, 243
for drawing squares with a solid or dotted outlines, 237
for drawRegion() method, 244
for editing lists, 71
examining content types and protocols at runtime, 313
example Ant build script, 25–27
for explicity setting timeout value to five seconds, 64
for figuring what size Images you need, 70
for finding amount of memory an object uses, 332
for finding available space on a file system, 121
for finding if a List element is selected, 71
for finding number of items in a form, 75
for finding size of a specific file, 121
for finding total size of all directory files, 121
for finding used up size of the storage area, 121
of GameCanvas loop to respond to key presses, 258
of GaugeMIDlet source code, 84–86
of GaugeTracker source code, 87–88
for getting access to message header information, 172
for getting access to message timestamp information, 173
for getting Bluetooth address and friendly name, 204
for getting just a file or directory name, 123
for getting list of categories supported by device, 132
for getting the Contact.EMAIL field, 135
for getting URL for open FileConnection, 122
for going to a specific subdirectory, 122
of Graphics class methods for drawing text, 238
of Graphics class methods used for blitting, 246
for HexCodec helper class, 352
implementation instantiating a pair of RC4 objects, 358
for implementing a CommandListener, 58
for information on your local Bluetooth stack, 199
for iterating through roots, 124
of Jargoneer MIDlet JAR manifest file, 32
for jumping to a particular Sprite frame, 264
for listing directory content, 122
for making a connection with HTTP GET, 146
for making your device discoverable, 200
for managing RecordStore's listeners, 112
for manipulating categories associated with contacts, 132–133
of message receive code when using blocking receive(), 171
method for changing collision rectangle, 266
of method for loading a 3D World .m3g file, 302
of method for obtaining the 3D World active Camera, 302
of method for obtaining the 3D World Background, 302
method for rendering integer arrays as images, 245
of method for simplifying discovery, 202
of methods called when keys are pressed and released, 247
methods for accessing title, 60
methods for designating a start content ID, 183
of methods for managing multipart message addresses, 183
methods for setting or getting the Date, 82
methods for testing security status of a connection, 204
methods for working with MMS message subjects, 184
of the methods of Background, 287

methods used for service discovery callback, 203
for MIDlet class, 31
of MIDlet for playing audio files, 309–311
of a MIDlet that demonstrates SimpleItem, 91
of a MIDlet that demonstrates StationSign, 101–102
for a MIDlet to seed PIM database with contacts, 138–140
of a MIDlet to send and receive SMS messages, 174–177
MMSMIDlet for sending and receiving MMS, 186–190
for a modal alert, 64
for modifying Contact field values, 137
new variables or methods in CLDC 1.1, 43–44
OBEX dating client-DateClient.java, 222–224
for obtaining a DatagramConnection, 158
for obtaining a FileConnection instance, 119
for obtaining an instance of a LocalDrive, 200
for obtaining an OBEX response code, 219
for obtaining FileConnection API version, 118
for obtaining file separator for file paths, 123
for obtaining Image instances, 69
for obtaining preferred attribute index, 136
for obtaining the singleton instance of Bluetooth manager, 200
for obtaining the value of a particular header, 218
for obtaining value of the last name of a Contact, 135
for opening a record store, 104–105
for packaging Jargoneer, 24
for packing colors into an integer, 236
for parsing and saving session ID, 153
for passing items to a Form, 73
for passing parameters with HTTP GET, 146–147
for PasswordMIDlet, a protected password client, 349–351
of the PasswordServlet class, 353–355
for permissions in MIDlet suite descriptors, 36
PianoCanvas source code, 306–308
for placing an Item at a specific index, 74
for playing sampled audio data, 308
for playing video using MMAPI, 323–325
for positioning and displaying video on your phone, 322
a preferences class that encapsulates file system access, 125–128
of QuatschCanvas as a Game API example, 268–272
for RecordFilter implementation, 113
for registering a listener with a Displayable, 58
for registering an ItemStateListener with a Form, 87
for registering PatchyMIDlet at runtime, 161
for registering ServiceRecord with the SDDB, 207
RemoteDevice instance security methods, 204
for removing all addresses in an address type, 183
for removing all addresses in the ‘to’, ‘cc’, and ‘bcc’ fields, 183
for removing items from a form, 74
for removing selective addresses, 183
for renaming a PIM list category, 132
for requesting a MIDlet wakeup call, 30
RetainedCanvas for interacting with a retained mod 3D world, 299–301
for retrieving a record store record, 107–108
for retrieving a string-valued header, 218
for retrieving MIDlet attribute value, 34–35
for retrieving subject of a server certificate, 158
for rotating a texture-mapped cube, 291–294
of samples write tone sequences, 318–321
for saving a server session ID cookie, 154–155
for seeing Canvas in action, 241–242
for sending a session ID to a server, 153
for sending MMS messages with MMSSender, 190–192
for sending SMS messages, 178–179

of a server loop listening for incoming connections, 160
for setting current position of Sprite's reference pixel, 266
for setting playback volume to half its maximum, 316
for setting the current drawing color, 92, 235
for setting the Dr. Quatsch reference pixel, 265
for setting the payload of the BinaryMessage, 169
for setting the payload with a text string, 170
showing contents of the Jargoneer directory, 16
showing how to place text on a Canvas, 238
showing iteration of the while loop within the run() method, 288
showing openPIMList() methods, 131
showing Transform methods, 288
showing typical use of RecordEnumeration interface, 114–115
of a simple custom item, 90
a simple MIDlet performing an HTTP POST, 150–152
simple MIDlet with a single command, 58–59
a simple servlet that responds to PostServlet, 152
for a simple session handling servlet, 156
of a simple tone sequence, 317
source code for Jargoneer, 13–15
source code for RecordMIDlet, 109–110
source code for StealthServlet, 362–363
source code for Sweep MIDlet, 252–254
source code of FCMIDlet, 128–129
for specifying dates, times, and time zone, 81
for specifying position of initial triangle, 284
of Sprite copy constructor, 267
for starting discovery for devices, 201
static method for discovering all root names, 124
for the static tile set on an existing TiledLayer, 261
StationSign custom item, 97–100
for StealthMIDlet, a data encryption MIDlet, 359–361
for StringItem labels, 78
for telling DiscoveryAgent to stop discovery, 201
for testing speed of applications, 332
for testing the source of command events, 68–69
that associates an appearance with a triangle submesh, 286–287
that creates and displays a simple off-screen image, 249–250
TravelList source code, 72–73
TriangleCanvas for rotation of a triangle in 3D, 281–283
of TwoAlerts, 65–66
of a typical animation, 251
of a typical Canvas implementation, 232
for updating registered ServiceRecord in the SDDB, 207
URLBuilder class for assembling GET URLs, 353
of usage of M3G for 3D graphics rendering, 277
using a font for drawing user-editable text, 93
using commit() method of Contact, 136
using Font class to retrieve an appropriate Font, 92
using GameCanvas for animation, 256–257
using GameCanvas's model inside a game loop, 256
using getDigestSize() method, 347
using getDiscoverable() method, 200
using getSizeAvailable() method, 106
using repaint() method, 232
using Runtime class, 44
using Spacer, 79
using System class, 44–45
using traverse() and traverseOut() methods, 96
code profiler
in the J2ME Wireless Toolkit, 332, 334
collision rectangle
method for changing, 266
collisions
handling, 266–267
color depth
defined, 53

colors
  packing a color into an integer, 236
  setting the current drawing color, 235
Command class
  GetCommandType() method provided by, 57
  methods provided by, 57
command events
  code for testing source of, 68–69
Command types
  table of, 57
commandAction() method
  calling, 58
  in IMPLICIT list event handling, 68–69
  importance of keeping uncomplicated, 59
CommandListener interface
  implementation of, 58
Commands
  adding or removing, 57
  creating, 57
  event handling with, 56–60
  priority scheme for, 57
  responding to, 58
  support for long labels on, 57
commit() method
  saving new Contact field values with, 136–137
Compact Flash cards, 117
confidentiality
  as part of data security, 344
configurations
  connected device, 4
  connected, limited device, 4–5
  in J2ME, 3–5
  partial list of for J2ME, 2–3
connected device configuration (CDC)
  uses for, 4
connected, limited device configuration (CLDC)
  uses for, 4–5
Connection interface
  family tree, 143
connection string
  defined, 144
connection types
  optional, 159–160
ConnectionNotFoundException, 30
connections
  responding to incoming, 160–163
  testing security status of, 204
Connector.open() method
  for creating new files and directories, 121
Connector.WRITE mode
  for creating new files, 121
constraints
  restricting TextBox user input with, 62
Contact
  Code for modifying field values, 137
  process for creating a new, 136–137
Contact interface
  accessor methods for data types on, 135
  attributes defined in, 136
  reading field values in, 135
  standard fields of a contact record, 133–134
ContactList
  using a method on to check for field support, 135
ContactList interface
  calling the removeContact() method on, 137
contact.NAME field
  creating a new contact with, 136–137
Contacts
  manipulating categories associated with, 132–133
  obtaining last name of, 135
  removing, 137
content area
  in CustomItem subclass, 89–91
content types
  common for audio data, 311–312
content types and protocols
  supported by Audio Building Block (ABB), 312–314
continuous gauges
  function of, 83–84
Controls
  obtaining a list of for a Player, 316
cookies
  for storing session ID on the client side, 152–153
  using for session tracking, 152–157
coordinate space
  on a Canvas, 233
copying
  Sprites, 267
corner submesh
  defining triangle strips for, 295

CornerCanvas
Building TriangleStripArray for, 297
code for adding texture coordinates to VertexBuffer, 297
code for rotating a texture-mapped cube, 291–294
creating a vertexArray in, 295
CornerMIDlet
rotating the corner of a cube, 291
createContact() method
function of on ContactList, 136–137
createIfNecessary parameter
for record stores, 104
createImage() factory methods
for Image class, 69–70
createImage() methods
for returning immutable Images, 70
createPlayer() method
function of in ABB, 312
obtaining a tone sequence Player with, 316–317
cryptographic solutions
and your data security needs, 344
cryptography
review of, 343
solutions for data security on the Internet, 344
cryptography packages
Bouncy Castle, 345–346
culling
adding code to disable, 289
the effect of, 280
experimentation with, 289
custom user interface
programming, 231–254
CustomItem
showing, hiding, and sizing, 93
CustomItem class
event handling, 93–94
introduction to, 89–91
support for game actions in, 93–94
CustomItem painting, 92–93
CustomItem subclass
code example of a simple, 90
content area in, 89–91
-d option
using with preverify, 17

D

data integrity
for applications, 344
data security
when using the Internet, 343–344
datagram connections
using, 158–159
DatagramConnection
code for obtaining, 158
DatagramConnection interface, 159
Date
Method for setting or getting, 82
DateClient class
for coding the Bluetooth client, 209–211
DateClient.java
code for an OBEX dating client, 222–224
DateField
DateField class
creating, 81
for entering dates, times, or both, 81
in Sun's MIDP 2.0 emulator, 82
dates and times
J2SE classes for specifying, 51–52
deallocate() method
function when called on a PREFETCHED or STARTED Player, 315
debugging
MIDlets, 12
default command
supported by Items, 76
default encoding for
for MIDP implementation, 48
DefaultColorPhone device emulator, 18
DefaultGrayPhone device emulator, 18
delete() method
deleting files or directories with, 122
for removing an element from a List, 70
for removing an item from a form, 74
deleteAll() method
for removing all items from a form, 74
for removing every element from a List, 71
deleteRecordStore() method
for removing a record store, 105
deleting
files and directories, 121–122
descriptor file. *See also* MIDlet descriptor; MIDlet suite descriptors
code for permissions in, 36
creating, 24

destroy() method
for releasing RecordEnumeration resources, 115
destroyApp() class
terminating MIDlet execution with, 29–30
Device combo box
choosing an emulator from, 18
device discovery
starting and stopping, 201
deviceDiscovered() notification method
function of, 201
devices
code for making discoverable, 200
a simpler way to discover, 202
dialog boxes
New Project, 16
digital fingerprint
defined, 344
digital signatures
as cryptographic solution for data security, 344
directories
creating new, 121
listing contents of, 122
renaming and deleting, 121–122
directorySize() method
for finding total size of all directory files, 121
discovery
method for simplifying, 202
using to create applications, 53
DiscoveryAgent
getting an instance of, 201
DiscoveryAgent instance
telling it explicitly to start device discovery, 201
DiscoveryAgent method
calling to terminate a search, 203
DiscoveryAgent.GIAC (General Inquiry Access Code)
for determining the type of inquiry, 201
DiscoveryAgent.LIAC (Limited Inquiry Access Code)
for determining the type of inquiry, 201
DiscoveryListener interface
methods for device discovery, 201
Display class
for keeping track of what is currently shown, 53–54
querying to determine its capabilities, 56
using to manage a device's screen, 55–56
Displayable instance
for changing display contents, 53–54
code for registering a listener with, 58
family of subclasses, 54
dotted outlines
code example for drawing, 237
double buffering
process for implementing, 249
for reducing flicker in drawing and animations, 249–250
Dr. Quatsch
code for setting reference pixel, 265
sprite source image, 263–264
drawImage() method
use of anchor points, 243–244
drawing color
setting current, 92, 235
drawLine() method
for rendering a straight line, 92
drawRegion() method
for rendering a region of an image, 244
drawRGB() method
for rendering integer arrays as images, 245–246
drawString() method
for rendering text, 92

E

Eclipse J2ME Plugin
website address for, 12
EDGE
support for SMS, 165
emulator controls
using, 18–19
emulators
J2ME Wireless Toolkit for testing applications, 18–19
encoding
function of, 48
enumerateRecords() method
for performing RecordStore queries, 113
working with RecordEnumeration interface, 114–115
Enumeration
using items() methods on PIMList to obtain, 132
event handling
with commands, 56–60
in CustomItem, 93–94

EXCLUSIVE lists
returning index of a selected element, 71
understanding, 67–68
EXCLUSIVE type
for ChoiceGroup, 86
exit() method
function of, 45
expanding layout value
for Form items, 77
ez-i service
deployed by LG TeleCom, 9

F

FCMIDlet
source code of, 128–129
field values
adding attributes to, 136
modifying, 137
file attributes
modifying, 120
File Connection Optional Package
for accessing plug-in flash memory cards, 117–123
JSR 75 requirements of, 124
relationship between CLDC 1.0 or 1.1 and, 118
using to store preferences to the file system, 124
file format
content type as, 311
file paths
obtaining file separator for, 123
file system roots
code for iterating through, 124
file systems
accessing, 119
top-level directory name, 119
FileBasedPreferences class
FCMIDlet that uses, 128–129
FileConnection API
Code for obtaining version number, 118
FileConnection interface
accessing file systems with, 119
exceptions input/output methods might throw, 120
methods for obtaining a stream, 119
obtaining an instance of, 118–119
FileConnection Optional Package
and security, 124
FileConnections
obtaining from GCF, 119
files
creating new, 121
renaming and deleting, 121–122
fileSize() method
for finding size of a specific file, 121
FileSystemRegistry
listing all available file systems with, 124
fillCells() method
for assigning the same tile to a range of tiles, 262
finalize() methods
execution of cleanup code in, 41
finally block
using to clean up code and release memory, 338–340
firmware
defined, 196
flags
for defining TextBox behavior, 62
flash memory cards
common formats, 117
listening for insertion and removal of, 123–131
_flashBacklight() method
function of, 56
float bias
using in VertexBuffer, 286
float scale
using in VertexBuffer, 286
floating-point support
lack of in CLDC 1.0, 39
flushGraphics() method
of 2D Graphics, 277
to get updates to appear on the screen, 255
Font class
constants in, 239
faces available in, 239–242
measuring text, 242–243
methods for measuring text, 242
for retrieving an appropriate font, 92
font faces
selecting in MIDP, 239–242
fonts
code demonstrating creation and use of, 240–241
using for drawing user-editable text, 93

Form layout
understanding, 75–86
Formatting classes
in CLDC/MIDP, 52
function of in J2SE, 51
Forms
creating advanced interfaces with, 73–88
code for parcing items to, 73
example of traversal and internal item traversal, 95
example with a single StringItem and Back command, 78
example with a single TextField and Back command, 79–80
importance of keeping uncomplicated, 74
registering an ItemStateListener with, 87
responding to item changes, 87–88
support for concept of focus, 94–96
understanding layout of, 75–86
forms and lists, 67–88
forward slash (/). *See* / (forward slash)
Foundation Profile specification, 5
frame sequences
in Sprite animation, 263–264
freeMemory() method
function of, 44

G

game actions
in MIDP, 247–249
support for in CustomItem class, 93–94
Game API
collision detection techniques, 266
overview, 255
for simplifying writing of 2D games, 255–273
special effects, 272
GameCanvas
vs. Canvas, 255
driving animation with, 255–257
game action bit constants in, 258
subclassing, 256
GameCanvas bit constants
table of, 258
GAP. *See* Generic Access Profile (GAP)
garbage collector
calling explicitly, 338
Gauge
Creating an interactive, 83
passing to Alert's setIndicator() method, 65
Gauge class
function of, 83–86
value settings, 84
Gauge instance
retrieving value of, 83
GaugeMIDlet source code
example, 84–86
GaugeTracker source code
code example, 87–88
gc() method
for running garbage collector, 44
GCF. *See* Generic Connection Framework (GCF)
Generic Access Profile (GAP)
for remote access to devices, 199
Generic Connection Framework (GCF)
connecting to the world with, 143–164
javax.microedition.io.Connector class as part of, 119
obtaining FileConnections from, 119
protocol specification for the connection string, 206–207
WMA API built around, 167–169
GET, HEAD, and POST requests
HTTP operations, 145–146
get() method
for obtaining a large data object from a server, 219
GET requests
aborting, 220
for obtaining a large data object from a server, 219
getAnimatedTile() method
for retrieving tile associated with an animated tile, 263
getBaselinePosition() method
for getting the location of the baseline, 242–243
getBorderStyle() method
function of, 56
getCell() method
for retrieving the tile index of a cell, 262
getColor() method
constants in the Display class, 92
function of, 56
retrieving current drawing color with, 236
getCommandType() method
provided by the Command class, 57

getContentType() method
  for finding content type of an existing Player, 314
getControls() method
  for obtaining a list of Player Controls, 316
getCurrent() method
  function of, 56
getDefaultTimeout() method
  getting default value for alerts with, 64
getDeviceClass() method
  function of in Bluetooth, 199
getDigestSize() method
  checking length of byte array with, 347
getDiscoverable() method
  function of in Bluetooth, 199–200
getDiscoveryAgent() method
  function of in Bluetooth, 199–200
getDisplay() method
  supplying a MIDlet reference to, 55–56
getDuration() method
  total time represented by audio clip returned from, 316
getFilter() method
  for returning a MIDlet filter, 163
getFont() method
  for getting a reference to the current font, 240
  in StringItem class, 79
getFrame() method
  for finding the current frame sequence index, 264
getFrameSequenceLength() method
  for getting the number of elements in a frame sequence, 264
getFriendlyName() method
  function of in Bluetooth, 200
getGameAction() method
  function of, 93
  for mapping physical keys to video game buttons, 247–249
getGraphics() method
  for modifying mutable Images, 69
  using Graphics returned from to draw on screen, 255
getGrayScale() method
  for finding the current grayscale value, 236
getInteractionModes() method
  constants, 94
  for determining device capabilities, 93–94
  finding a devices traversal capabilities with, 96
getKeyName() method
  for getting text description of a given key code, 247
getKeyStates() method
  for returning the current state of keys in GameCanvas, 257
getLabel() method
  inherited from Item, 79
  in Item class, 75
  provided by the Command class, 57
getLastModified() method
  using in record stores, 106
getLayerAt() method
  retrieving a layer at a certain position with, 260
getLayout() method
  for accessing Item class layout directive, 77
getLength() method
  for obtaining the value from the standard OBEX header, 219
getLocalAddress() method
  used by UDPDatagramConnection, 159
getLocalPort() method
  used by UDPDatagramConnection, 159
getLongLabel() method
  provided by the Command class, 57
getMediaTime() method
  finding current media time with, 316
getMIDlet() method
  for returning a MIDlet name, 163
getMinimumHeight() method
  retrieving Item minimum size with, 76
getMinimumWidth() method
  retrieving Item minimum size with, 76
getPrefContentWidth() method
  function of, 89
getPreferredHeight() method
  using for Items, 77
getPreferredWidth() method
  using for Items, 77
getProperty() method
  function of, 45

getRawFrameCount() method
for getting number of frames in a Sprite, 263
getRecord() method
retrieving record store records with, 108
getRefPixelX() method
for finding current location of Sprite's reference pixel, 266
getRefPixelY() method
for finding current location of Sprite's reference pixel, 266
getRuntime() method
for getting a single Runtime instance, 44
getSize() method
calling to get number of layers, 260
getSizeAvailable() method
for checking on available record store space, 106
getState() method
retrieving a Player's current state with, 315
getText() method
for accessing and adjusting string value, 79
getTitle() method
for accessing title, 60
getType() method
for obtaining the value from the standard OBEX header, 219
getValue() method
retrieving value of a Gauge instance with, 83
getVersion() method
for retrieving record store version number, 106
getVisible() method
using to access a layer's visibility, 259
GIAC. *See*Discovery.Agent GIAC
GPRS
support for SMS, 165
Graphics class
advanced image rendering, 244–245
current line style for drawing shape outlines and lines, 236–237
drawing images in, 243–244
drawing shapes, text and images on a Canvas with, 233–246
method used for blitting, 246
methods for drawing and filling shapes, 233–234
methods for drawing text, 237–238
MIDP's vs. J2SE's, 233
rectangular clipping shape maintained by, 246
using getDisplayColor() method in, 236
using text anchor points to draw text, 237–239
Graphics object
drawing a TiledLayer on, 260–261
for drawing on content area of an item, 90
for drawing shapes, text and images on a Canvas, 232–233
Graphics3D class
code for obtaining instance of, 276
greyscale value
getting current, 236
GSM
support for SMS, 165

H

hasNextElement() method
for finding if there is a next record, 114
hasPointerEvents() method
for verifying support for pointer events, 249
hasPointerMotionEvents() method
for verifying support for pointer events, 249
HEAD requests
in HTTP operations, 146
headers
code for working with other message headers, 184
HeaderSet interface
adding a user-defined string-typed header to, 218
method for adding a user-defined header to, 218
using to set and get values of user-defined headers, 218
HexCodec helper class
code for, 352
HI Corporation
.m3g export utility by, 298
hideNotify() method
calling of by MIDP implementation, 93
horizontal values
for layout of Form items, 77
HTTP connections
required support for by MIDP 2.0, 144

HTTP GET
making a connection with, 146–149
passing parameters to the server with, 146–147
HTTP operations
code for retrieving an image from the Internet, 147–149
GET, HEAD, and POST requests, 145–146
HTTP POST
posting a form with, 149–152
HttpConnection interface, 144
HttpConnection methods, 144
HttpConnection object
calling getHeaderField() to check for cookies on, 153
HTTPS
support built into the MIDP platform, 345
using, 157–158
HTTPS connection string
code for constructing, 158
HYPERLINK appearance mode, 79
Hypertext Transfer Protocol (HTTP)
parameters, 145
requests and responses, 145
review of, 145–146
Hypertext Transfer Protocol (HTTP) connections. *See also* HTTP connections; HTTP GET; HTTP operations; HTTP POST
required support for by MIDP 2.0, 144

I
i-Appli API
developed by NTT DoCoMo, 9
IBM WebSphere Studio Device Developer
website address, 12
identityHashCode() method
function of, 45
IDEs
vendors and open souce communities for, 12
Image class
createImage() factory methods for, 69–70
Image instances
code for obtaining, 69
image rendering
advanced, 244–245
Image3D class
format parameters, 295
for texture mapping a cube exterior, 295–296
imageElements parameter
function of, 69
ImageItem
associated data and function of, 80–81
controlling appearance of, 79
creating, 81
imagelength, 69
ImageLoader MIDlet
code for retrieving an image from the Internet, 147–149
imageoffset, 69
Images
Converting a byte array to, 326
creating from a portion of another Image, 70
creating mutable and immutable, 70
images
drawing in Graphics class, 243–244
as integer arrays, 245–246
immediate mode
vs. retained mode, 297–303
immutable Images, 69
code for creating, 70
i-mode
deployed by NTT DoCoMo, 9
IMPLICIT lists
code for returning index of a selected element, 71
event handling for, 68–69
understanding, 67–68
includeHidden flag
function of, 122
incoming connections
responding to, 160–163
incremental gauges
function of, 83–84
Industrial, Scientific, and Medical (ISM) frequency band
operation of Bluetooth radio hardware at, 195
infrared communications
and OBEX, 215–220
init() method
for setting up the light and camera, 287–288

initDisplayMode() method
using to create a video display, 322–323
INITIAL_CAPS_SENTENCE flag
function of, 62
INITIAL_CAPS_WORD flag
function of, 62
InputStream
accessing a resource file as, 116
creating an image from, 69
InputStreamReader
function of, 48
inquiryCompleted() method
function of, 201
insert() method
for adding an item in the middle of a form, 74
for adding elements to lists at a given index, 70
integer arrays
images as, 245–246
method for rendering as images, 245
interactive gauge
function of, 83
interfaces
creating advanced with Forms, 73–88
included in java.util package, 49–51
J2SE SDK 1.4.2, CLDC 1.0, CLDC 1.1, 40
java.io in J2SE SDK 1.4.2 and CLDC 1.0 and 1.1, 45–46
internal traversal
function of, 95
Internet
data security, 343–344
Internet Mail Consortium
website address, 133
interrupt() method
in CLDC 1.0 and 1.1, 42
invalidate() method
function of, 93
isColor() method
function of, 56
isDoubleBuffered() method
for checking if a Canvas is double buffered, 249
isHidden() method
to determine if a file or directory is hidden, 120
isKeptUpdated() method
for finding if RecordEnumeration is automatically updated, 115
ISM frequency band
operation of Bluetooth radio hardware at, 195
isShown() method
in Displayable interface, 56
Item class
contents of, 75–86
getLabel() and setLabel() methods, 75
for passing items to a Form, 73
Item pantry
toolbox of items to build forms, 75
item traversal, 94–96
ItemCommandListener interface
single method contained in, 76
items
custom, 89–102
managing, 74–75
Items
commands for, 75–76
in Forms, 73
managing commands on, 76–77
placing at a specific index, 74
requesting a new line before or after in Forms, 77–78
responding to changes to, 87–88
ItemStateListener
registering with a form, 87

J

J2ME (Java 2 Platform, Micro Edition)
configurations, profiles, and optional APIs, 2–3
introduction to, 1–10
understanding, 1–3
J2ME stack, 1
J2ME Wireless Toolkit (J2MEWTK)
creating a new project with, 15–17
devices, 18
diagnostic tools in, 332–335
packaging your application in, 23
website address for downloading, 11
J2ME Wireless Toolkit emulators
buttons on, 19
results if MediaInformationMIDlet is run on, 314
for testing applications, 18–19

J2MEWTK. *See* J2ME Wireless Toolkit (J2MEWTK)
J2SE classes
  vs. CLDC classes, 48
  for specifying dates and times, 51–52
J2SE Collections API
  lack of support for in CLDC, 51
J2SE SDK 1.4.2
  interfaces, 40
  java.io classes in, 46
  java.io interfaces in, 45–46, 47
  java.lang package classes and interfaces, 40–41
  java.lang.ref package classes, 41
  Vector and Hashtable classes, 51
Jargon File
  website address for information about, 12
Jargoneer MIDlet
  advantages of newer architecture, 22–23
  architecture of, 22
  code for showing directory contents, 16
  creating source code for, 12–15
  creating a TextBox, 21
  packaging, 24
  tour of features, 20–21
Java 2 Platform, Standard Edition (J2SE) APIs
  specification of strict subset of in J2ME, 1–3
Java API for Bluetooth
  classes and interfaces in the javax.bluetooth package, 199–204
  implementation of, 195–196
  relationship between MIDP, CLDC and, 196
  specification for, 196
Java API for OBEX
  specification for, 196
Java Archive (JAR)
  manifest information, 23–24
Java Community Process (JCP)
  website address for, 2
Java Cryptography (Jonathan Knudsen, O'Reilly, 1998)
  for information about cipher modes, 358
Java for small devices. *See* J2ME (Java 2 Platform, Micro Edition)
Java Media Framework (JMF)
  MMAPI as pint-sized version of, 305
Java source code
  creating for Jargoneer MIDlet, 12–15
Java Specification Requests (JSRs)
  website address for list of current, 2
Java Technology for the Wireless Industry (JTWI), 6
Java Virtual Machine (JVM)
  understanding J2ME for, 1–3
java.io package
  classes and interfaces, 367–373
  classes in both J2SE and CLDC/MIDP, 45–47
  streams in, 45–48
java.io.ByteArrayInputStream class, 367
java.io.ByteArrayOutputStream class, 368
java.io.DataInput interface, 368
java.ioDataInputStream class, 368–369
java.io.DataOutput interface, 369
java.io.DataOutputStream class, 370
java.io.InputStream class, 370
java.io.InputStreamReader class, 371
java.io.OutputStream class, 371
java.io.OutputStreamWriter class, 371
java.io.PrintStream class, 372
java.io.Reader class, 372–373
java.io.Writer class, 373
java.lang package
  classes and interfaces, 39–41, 373–383
java.lang package classes
  J2SE SDK 1.4.2, CLDC 1.0, CLDC 1.1, 40
java.lang package interfaces
  J2SE SDK 1.4.2, CLDC 1.0, CLDC 1.1, 41
java.lang.Boolean class, 373
java.lang.Byte class, 374
java.lang.Character class, 374–375
java.lang.Class class, 375
java.lang.Double class, 375–376
java.lang.Double wrapper
  lack of support for in CLDC 1.0, 39
java.lang.Float class, 376–377
java.lang.Float wrapper
  lack of support for in CLDC 1.0, 39
java.lang.Integer class, 377
java.lang.Long class, 378
java.lang.Math class, 378–379
  in CLDC, 43–44
java.lang.Object
  as root of every Java class, 41
java.lang.Object class, 379
java.lang.ref package classes, 41, 384
java.lang.ref.Reference class, 384

java.lang.ref.WeakReference class, 384
java.lang.Runnable interface, 379
java.lang.Runtime class, 379
  methods for testing memory use, 331–332
java.lang.Short class, 380
java.lang.String class, 380–381
java.lang.StringBuffer class, 381–382
java.lang.System class, 382
  for testing speed of applications, 332
java.lang.Thread class, 383
java.lang.Throwable class, 383
java.util package
  classes and interfaces, 384–389
  classes and interfaces for J2SE and CLDC/MIDP, 49–51
java.util.Calendar class, 384–385
java.util.Date class, 385–386
java.util.Enumeration interface, 386
java.util.Hashtable class, 386
java.util.Random class, 386–387
java.util.Stack class, 387
java.util.Timer class, 387
java.util.TimerTask class, 388
java.util.TimeZone class, 388
java.util.Vector class, 388–389
javax.bluetooth package
  classes and interfaces in, 199–204
javax.microedition.io package
  classes and interfaces, 389–395
javax.microedition.io.CommConnection interface, 389
javax.microedition.io.Connection interface, 390
javax.microedition.io.Connector class, 389–390
  accessing file systems using a method of, 119
  function of, 144
javax.microedition.io.ContentConnection interface, 390
javax.microedition.io.Datagram interface, 390
javax.microedition.io.DatagramConnection interface, 390–391
javax.microedition.io.file package
  File Connection Optional Package in, 117–123
javax.microedition.io.file.FileSystemListener
  listener interface, 123
javax.microedition.io.file.FileSystem Registry class
  for managing listeners, 123
javax.microedition.io.HttpConnection interface, 391–392
javax.microedition.io.HttpsConnection interface, 392
javax.microedition.io.InputConnection interface, 393
javax.microedition.io.OutputConnection interface, 393
javax.microedition.io.PushRegistry class, 393
  using static methods in to register for push connections, 160
javax.microedition.io.SecureConnection interface, 393
javax.microedition.io.SecurityInfo interface, 394
javax.microedition.io.ServerSocketConnection Interface, 394
javax.microedition.io.SocketConnection interface, 394
javax.microedition.io.StreamConnection interface, 394
javax.microedition.io.StreamConnectionNotifier interface, 395
javax.microedition.io.UDPDatagramConnection interface, 395
javax.microedition.lcdui package
  classes and interfaces, 395–411
  MIDP user interface classes in, 53–55
javax.microedition.lcdui.Alert class, 395–396
  constructors, 64
javax.microedition.lcdui.AlertType class, 396
javax.microedition.lcdui.Canvas class, 396–397
javax.microedition.lcdui.Choice interface, 397–398
javax.microedition.lcdui.ChoiceGroup class, 398
javax.microedition.lcdui.Command class, 399
javax.microedition.lcdui.CommandListener interface, 399
javax.microedition.lcdui.CustomItem class, 399–400
javax.microedition.lcdui.DateField class, 400
javax.microedition.lcdui.Display class, 401
javax.microedition.lcdui.Displayable class, 401–402

javax.microedition.lcdui.Font class, 402
javax.microedition.lcdui.Form class, 403
  for creating Forms, 73
  description of layout algorithm in documentation, 75
javax.microedition.lcdui.game package
  classes, 411–413
  Game API classes in, 255
  MIDP user interface classes in, 53–55
javax.microedition.lcdui.game.GameCanvas class, 411
javax.microedition.lcdui.game.Layer class, 259, 411–412
javax.microedition.lcdui.game.LayerManager class, 412
javax.microedition.lcdui.game.Sprite class, 412–413
javax.microedition.lcdui.game.TiledLayer class, 413
javax.microedition.lcdui.Gauge class, 403–404
javax.microedition.lcdui.Graphics class, 404–405
javax.microedition.lcdui.Image class, 69–70, 405
javax.microedition.lcdui.ImageItem class, 406
javax.microedition.lcdui.Item class, 406–407
javax.microedition.lcdui.ItemCommandListener interface, 407
javax.microedition.lcdui.ItemStateListener interface, 407
javax.microedition.lcdui.List class, 407–408
javax.microedition.lcdui.Screen class, 408
javax.microedition.lcdui.Spacer class, 408
javax.microedition.lcdui.StringItem class, 409
javax.microedition.lcdui.TextBox class, 409
javax.microedition.lcdui.TextField class, 410
javax.microedition.lcdui.Ticker class, 410–411
javax.microedition.m3g package
  3D API classes in for rendering 3D graphics, 276–277
javax.microedition.media package
  classes and interfaces, 414–415
javax.microedition.media.Control interface, 414
javax.microedition.media.control package
  class relationships, 312
  interfaces, 415–416
javax.microedition.media.Controllable interface, 414
javax.microedition.media.control.ToneControl interface, 415–416
javax.microedition.media.control.VolumeControl interface, 416
javax.microedition.media.Manager class, 414
javax.microedition.media.manager package
  method for playing tones, 305
javax.microedition.media.Player interface, 414–415
javax.microedition.media.PlayerListener interface, 415
javax.microedition.midlet.MIDlet class, 416
javax.microedition.pki package, 417
javax.microedition.rms package
  classes and interfaces, 417–419
javax.microedition.rms.RecordComparator interface, 417
javax.microedition.rms.RecordEnumeration interface, 417
javax.microedition.rms.RecordFilter interface, 418
javax.microedition.rms.RecordListener interface, 418
javax.microedition.rms.RecordStore
  record stores represented by instances of, 103
javax.microedition.rms.RecordStore class, 418–419
Jave Cryptography (O'Reilly, 1998)
  by Jonathan Knudsen, 344, 358
JMF. *See* Java Media Framework (JMF)
JSR 120
  website address, 166
JSR 135
  MMAPI details in, 305
JSR 177 (Security and Trust Services for J2ME)
  website address, 346
JSR 184
  optional API for rendering 3D graphics, 275–303
JSR 185
  website address, 6
JSR 205
  website address, 166
JSR 248
  submitted by Nokia and Vodafone, 6

JSR 68
  definition of Building Blocks, 6
JSR 75
  file systems and PMI databases addressed by, 117
  requirements of, 124
JSR 82 (Java API for Bluetooth Wireless Technology), 196
JTWI specification. *See Java Technology for the Wireless Industry (JTWI)*
JTWI-compliant devices
  current specification for, 6
JVM. *See* Java Virtual Machine (JVM)

K

keepUpdated parameter
  of RecordStore's enumerateRecords() method, 115
key events
  for Canvas, 246–247
  suppressing for better performance, 256
  using game actions to map to events, 247–249
key states
  polling, 257–259
KeyParameter object
  function of, 358
Kittyhawk API
  developed by LG TeleCom, 9
Knudsen, Jonathan
  Jave Cryptography (O'Reilly, 1998) by, 344, 358
KToolbar
  setting BTMIDlet properties with, 208
  starting, 15
KVM
  function of, 4

L

latched key states, 258–259
LayerManager class
  for managing layers, 259–260
layers
  accessing visibility of, 259
  adding to a specific location, 259
  adding to the bottom of the list, 259
  code for adjusting the position of, 259
  managing, 259–260
  removing, 260
  understanding, 259
layout values
  for Form items, 77
LAYOUT_2 flag
  using in Item class, 77
LG TeleCOM
  Kittyhawk API developed by, 9
LIAC. *See* DiscoveryAgent.LIAC
Light object
  in M3G, 288
line styles
  constants for in the Graphics class, 236–237
List class
  creating, 69
List selections
  working with, 71
listConnections() method
  for returning all registered network connection strings, 163
listener
  code for registering with a Displayable, 58
  notification of when command is invoked, 58
listener interface
  javax.microedition.io.file.FileSystemListener, 123
listRecordStores() method
  for finding all record stores in a MIDlet suite, 105
lists
  creating, 69
  editing, 70–71
  understanding types of, 67–68
  using, 67–73
lists and forms, 67–88
Loader class
  using an M3G to load a retained mode world, 301–302
LocalDevice
  obtaining and instance of, 200
login() method
  as meat of protected password algorithm, 349
lookupPassword() method
  used by servlet to look up user's password, 355
loops
  optimizing for application speed, 337

M

M3G
  feeding with triangle information, 281–284
M3G 3D API
  rendering a rotating triangle with, 278–279
M3G API
  classes for setting up 3D scenes, 284
  dependence on CLDC, MIDP, and Open GL ES, 276
  steps for using retained mode in, 298
M3G API 1.0. *See also* Mobile 3D Graphics API (M3G)
  website address for description of, 275
.m3g file
  creating, 298
  method for loading 3D World, 302
Manager class
  methods to find content types and protocols are supported, 312
  reasons why MediaException is thrown by, 312
Material
  possible values for first parameter of setColor() method of, 287
Material color
  possible values for specifying the reflective quality of, 287
Math class
  in CLDC, 43–44
media time
  of Players, 315–316
MediaControlSkin device emulator, 18
MediaException
  thrown when Manager can't handle data or protocol, 312
MediaInformationMIDlet
  results if run on J2ME wireless toolkit emulator, 314
memory. *See* nonvolatile memory; volatile memory
memory monitor
  in the J2ME Wireless Toolkit, 332–333
Memory Stick cards, 117
memory use
  creating and discarding objects, 335–336
  effect of Strings and StringBuffers on, 336
  failing gracefully, 336
  optimizing, 335–337
  using java.lang.Runtime methods for testing, 331–332
message digests
  as cryptographic solution for data security, 344
  process for protecting passwords, 346
  protecting passwords with, 346–356
  using, 346–347
message headers
  examining, 172–173
message parts
  accessing content of, 185
  adding to a multipart message, 184–185
  found in multipart messages, 182
  managing, 184
MessageConnection class
  adding a MessageListener on, 172
  code for sending SMS messages, 169
  for creating an empty message, 168
  for receiving SMS messages, 170–171
MessageListener interface
  callback method, 172
MessagePart
  accessing, 185
MessagePart interface
  methods for reading content ID and location, 183
MicroEdition-Configuration attribute, 33
microedition.configuration property, 45
microedition.encoding property, 45
microedition.io.file.FileConnection.version property
  for confirming availability of FileConnection API, 118
microedition.pim.version
  checking for, 131
microedition.platform property, 45
MicroEdition-Profile attribute, 33
microedition.profiles property, 45
MIDlet audio files
  code for playing, 309–311
MIDlet class
  as bridge to outside world, 31
  method for checking permissions, 35
MIDlet descriptor
  creating, 24
MIDlet JAR manifest file
  attributes that must be included, 32–33
  information in, 32–33
  for Jargoneer, 32
MIDlet properties, 34–35
  for OBEXMIDlet and OBEX2 projects, 221

MIDlet suites
anatomy of, 31
permissions in descriptors, 36–37
private and shared record stores between, 104
protection domains, 36
security, 35–37
steps for packaging, 32
MIDlet-Data-Size attribute, 33
MIDlet-Description attribute, 33
MIDlet-Extensions attribute, 33
MIDlet-Icon attribute, 33
MIDlet-Info-URL attribute, 33
MIDlet-n attribute, 32
MIDlet-Name attribute, 32
MIDlet-Permissions attribute, 33
MIDlet-Permissions-Opt attribute, 33
permissions in, 37
MIDlets
all about, 29–37
basic function of typical, 54
building, 11–27
code for playing audio files, 309–311
code for requesting launch at a later date, 30
compiling, 15–17
debugging, 12
design tips for creating networked, 157
life cycle of, 20, 29–30
packaging, 31–35
packaging your application, 23–24
for requesting a wakeup call for, 30
running, 18
setting the property to a URL, 157
states of and the transitions between, 29–30
tools for building, 11–12
transferring to a real device, 27
MIDlet-Vendor attribute, 32
MIDlet-Version attribute, 32
MIDP. *See also* MIDP 2.0 specification (JSR-118); Mobile Information Device Profile (MIDP)
advantages of, 8–9
creating a user interface, 53–66
game actions in, 247–249
minimum screen size mandated by, 53
permission names defined by, 163
platform fragmentation concerns in MIDP community, 9–10
relationship between Java API for Bluetooth, CLDC and, 196
tour of features, 20–23
user interface classes in, 53–55
vendors, 9
versions of, 6
MIDP 1.0 (JSR 37)
vs. MIDP 2.0 specification (JSR-118), 6
MIDP 2.0
kinds of gauges in, 84
tone sequence player in, 316–321
MIDP 2.0 specification (JSR-118), 5–6
vs. MIDP 1.0 (JSR 37), 6
MIDP alerts. *See* alerts; modal alerts; timed alerts
MIDP API reference
for classes and interfaces, 367–419
MIDP applications
anatomy of, 6–8
midp emulator
running a preverified class file with, 18
MIDP implementation
calling of hideNotify() method by, 93
calling of showNotify() method by, 93
calling of sizeChange() method by, 93
default encoding for, 48
MIDP packages
CLDC 1.1 and MIDP 2.0, 7
MIDP record stores
persistant storage 1, 103–116
MIDP reference implementation
packaging your application in, 23–24
website address for downloading, 11
MIDP software components, 7
MIDP user-interface classes
threading with, 250–254
minimum size
for Items, 76–77
mkdir() method
calling for creating a new directory, 121
MMAPI
details in JSR 135, 305
playing MP3 music through, 311
quick start, 305–311
using to play video on your phone, 321–325

MMAPI media concepts, 311–312
MMS. *See* Multimedia Message Service (MMS)
MMS messages. *See also* Multimedia Message Service (MMS)
  adding a subject to, 184
  a MIDlet to send and receive, 185–193
  working with other message headers, 184
MMS send and receive
  methods for testing, 192–193
MMS testing
  information for testing on WMA console, 192–193
MMSMIDlet
  code for, 186–190
  testing MMS send and receive, 192–193
  testing using two emulator instances, 193
MMSSender class
  sending MMS messages with, 190–192
  source code for, 190–192
Mobile 3D Graphics API (M3G)
  for displaying and manipulating 3D graphics on mobile devices, 275–303
  overview of, 275–277
  website address for information about, 275
Mobile Information Device Profile (MIDP). *See also* MIDP
  characteristics of, 5–6
Mobile Multimedia API (MMAPI). *See also* MMAPI
  removing support leaving only MIDP audio, 321
  support for by JTWI-compliant devices, 6
mobile phones
  understanding J2ME for, 1–3
Mobile Service Architecture for CDC
  JSR-248 for, 6
modal alerts
  dismissing, 64
  function of, 63
Motorola
  MIDP telephone produced by, 9
MP3 music
  playback through MMAPI, 311
Multimedia Message Service (MMS)
  phone networks found in, 181
  support for in WMA 2.0, 165
Multimedia Message Service Center (MMSC)
  processing of multiple recipient messages by, 182
multipart messages
  anatomy of, 182
  methods for managing addresses associated with, 183
  vs. SMS messages, 182
  working with, 182–184
MultipartMessage
  code for adding a new message part to, 185
  as subinterface of Message, 182
MULTIPLE lists
  understanding, 67–68
MULTIPLE type
  for ChoiceGroup class, 86
multithreading
  and animation, 250–254
  in CLDC, 42
mutable Images
  creating, 70
  modifying, 69

N

native methods
  lack of support for in CLDC, 42
navigation buttons
  on J2ME Wireless Toolkit emulator, 19
NetBeans IDE 4.x
  website address, 12
network connections
  with the generic connection framework, 143–164
  importance of releasing to free up memory, 338–340
  permissions for, 163–164
network data
  protecting, 343–366
  securing, 356–364
network data security
  HTTPS is almost everything you could want, 345
  TLS for, 345
network monitor
  in the J2ME Wireless Toolkit, 334–335
networked MIDlets
  design tips for creating, 157
networking
  with devices near you, 196–197
New Project dialog box, 16
newMessage() class factory
  creating a new message part with, 184–185

newMessage() method
for creating new messages, 168–169
specifying a message type for, 169
nextFrame() method
using in Sprite animation, 264
nextRecord() method
for moving the current position in RecordEnumeration, 115
nextRecordID() method
calling to retrieve next record's ID, 114–115
Nokia Developer's Suite for J2ME
website address for, 12
NON_PREDICTIVE flag
function of, 62
noninteractive gauges
types of, 83–84
nonvolatile memory
defined, 3
normals
defining in 3D rendering, 285
NTT DoCoMo
MIDP vendor, 9
numAlphaLevels() method
function of, 56
numColors() method
function of, 56
NUMERIC TextBox
limitations of, 62

O

OBEX (Object Exchange protocol)
and Bluetooth, 195–229
communications using PUT or GET, 219–220
function of, 216
getting the current connection ID, 216
infrared communications and, 215–220
obtaining a response code, 219
obtaining client and server connections, 220
partial list of response codes, 218
user-defined header types, 217
OBEX APIs
ways to communicate using, 216
OBEX dating service
coding OBEXMIDlet.java, 224–229
coding the client, 221–224
implementing using OBEX over infrared, 220–229
OBEX headers
communications using, 217–219
OBEX over IrDA
obtaining client and server connections, 220
OBEX over RFCOMM/Bluetooth
support for, 216
OBEX over TCP/IP
support for, 216
OBEX requests
API methods and descriptions, 217
communicating using the OBEX APIs, 216
OBEX2 project
MIDlet properties for, 221
OBEXMIDlet project
MIDlet properties for, 221
OBEXMIDlet.java
code for an OBEX dating service, 224–229
obfuscator. *See* bytecode obfuscator
object finalization
methods in CLDC, 41–42
objects
effect of creating and discarding on memory use, 335–337
using arrays instead of for speed optimizations, 337–338
Objects tab
for viewing objects and their memory, 333
OK command
creating a standard, 57
oneshot permissions, 36
openDataInputStream() method
for obtaining a DataInputStream, 219
openDataOutputStream() method
for obtaining a DataOutputStream, 219
OpenGL ES
implementation of M3G 3D engine with, 275–276
website address for information about, 276
openInputStream() method
for obtaining an InputStream, 219
openOutputStream() method
for obtaining an OutputStream, 219
for specifying a byte offset for writing to a file, 119
openPIMLIst() methods
for obtaining a PIM list, 131
openRecordStore() method
for creating a shared record store, 105

optional APIs
partial list of for J2ME, 3
OR operator
for combining flags with other constraints, 62
org.bouncycastle.crypto.StreamCipher interface
stream ciphers represented by, 358
outlines
drawing dotted, 237
OutOfMemoryErrors
freeing up memory to resolve, 336
OutputStreamWriter
function of, 48
over-the-air (OTA) provisioning
for transferring MIDlet suites to a real device, 27

P

Pacer class
MIDlet that uses PacerCanvas class, 234–235
PacerCanvas class
code demonstrating simple drawing and filling, 234
pagers
understanding J2ME for, 1–3
paint() method
called to show contents of the Canvas, 232
calling to render an item, 89
CustomItem painting with, 92–93
for drawing scene's represented by LayerManager layers, 260
PANs (Personal Area Networks). *See* Personal Area Networks (PANS)
parameters
format for the Image3D constructor, 295
for HTTP clients, 145
passing to the server with HTTP GET, 146–147
PASSWORD flag
function of, 62
PasswordMIDlet
source code for, 349–351
passwords
necessity of on small devices, 63
the problem with, 346
protecting with a message digest, 346–356
suggested enhancements for protection of, 355–356
PasswordServlet class
for implementation of a protected password servlet, 353–355
PatchyMIDlet
the push registry entry for, 161
registering at runtime, 161
testing the push notification for, 162–163
website address for downloading, 160
path and URL information
method for getting, 122–123
pause() method
absence of in CLDC, 42
pauseApp() class
for suspending MIDlet execution, 29–30
PDA Profile (PDAP)
design of, 5
PDAs. *See* personal digital assistants (PDAs)
PeekAndPick application
example of network interactions from, 334–335
performance tuning
applications, 331–341
permissions
MIDlet suite security provided by, 35
for network connections, 163–164
types of, 36
persistant storage
file connection and PIM API, 117–142
MIDP record stores, 103–116
minimum size in MIDP specification, 103
overview, 103–104
Personal Area Networks (PANs)
creating with Bluetooth, 195–229
discovering devices or services in, 201
different interactions possible between devices in, 197
Personal Basis Profile
and Personal Profile, 5
personal digital assistants (PDAs)
understanding J2ME for, 1–3
Personal Information Management (PIM). *See* PIM (Personal Information Management) databases
PersonalJava
website address for, 5
PianoCanvas
source code, 306–308

piconet
Bluetooth network as, 195–196
pictures
snapping on a camera phone, 325–329
PIM database
code for a MIDlet to seed with contacts, 138–140
PIM lists
accessing records via an Enumeration of PIMItems, 132
adding new categories to, 132
deleting categories from, 132
manipulating categories, 132–133
obtaining items from, 131–132
opening, 131–142
renaming categories, 132
PIM Optional Package
determining if available, 131
major class and interfaces of KSR 75 and, 130
pipe (|) character separator
for storing a key and value pair in a record, 110
PLAIN appearance mode, 79
plaintext
conversion to ciphertext for data security, 344
platform fragmentation
concerns in MIDP community, 9–10
platform standardization, 6
platformRequest() method
for MIDlet class, 31
Player events
listening for, 316
Player tones and tone sequences, 316–321
PlayerListener
method called by with a variety of informational messages, 316
Players
controlling, 315–316
finding content type of, 314
life cycle of, 314–315
methods for adding and removing listeners, 316
REALIZED, 314–315
UNREALIZED, 314–315
playFromResource() method
changing to play MP3 music from a resource file, 311
playTone() method
function of, 305
PMI (Personal Information Management) databases
addressed by JSR75, 117
PNG files, 69
pointer events, 249–250
points in time
specifying in CLDC/MIDP, 52
specifying in J2SE classes, 51
polling
defined, 258
POPUP type
for ChoiceGroup, 86
portability
of MIDP, 8
POST requests
in HTTP operations, 146
postRotate() method
for Transforms, 289
PostServlet
Simple servlet that responds to, 152
Preferences class
for doing all RecordStore work, 109–112
preferred attribute
obtaining index corresponding to, 136
preferred size
default values for Items, 76–77
prefetch() method
calling on a newly created Player, 315
PREFETCHED state
for Players, 315
preRotate() method
for Transforms, 289
preverifying
class files, 17
prevFrame() method
for moving backward in a Sprite sequence, 264
previousRecord() method
for moving the current position in RecordEnumeration, 115
previousRecordID() method
for moving the current position in RecordEnumeration, 115
processBytes() method
calling to encrypt data, 358

profiles
current, 5
Mobile Information Device Profile (MIDP), 5–6
partial list of for J2ME, 3
ProGuard
downloading, 25
protected password protocol
implementing, 347–355
simple form collecting a user name and password, 348
protection domains
for MIDlet suites, 36
push connections
how a MIDlet may register for, 160
push notification
testing, 162–163
PushRegistry
function of, 30
put() method
for initiating a PUT request, 219
PUT requests
aborting, 220
code for initiating, 219

Q

QuatschCanvas. *See also* Dr. Quatsch
a Game API example, 267–272
QuatschMIDlet. *See also* Dr. Quatsch
running in an emulator, 268
QwertyDevice device emulator, 18

R

radio connectivity technology
for creating PANs, 195
RC4 objects
simple implementation instantiating a pair of, 358
RC4 symmetric encryption algorithm
for encrypting and decrypting data, 356
Reader character stream
in MIDP for working with Unicode characters, 48
realize() method
calling on a newly created Player, 315
REALIZED state
for Players, 314–315
receive() method
syntax for, 171
receiver thread
creating to receive messages in an application, 171
record stores. *See also* MIDP record stores
adding records to, 107
changing authorization mode and writable flags of, 105–106
changing bytes in, 106
code for accessing shared, 106
creating a shared, 105
createIfNecessary parameter for, 104
defined, 103
listening for record changes, 112
managing, 104–106
moving through selected records, 114–115
opening, 104–105
performing RecordStore queries on, 113–115
private and shared between MIDlet suites, 104
retrieving records, 107–108
retrieving version and timestamp for, 106
sharing, 105–106
use of authMode and writable parameters in, 105
recordAdded() method
for RecordListener interface, 112
recordChanged() method
for RecordListener interface, 112
RecordComparator interface
code for implementing, 113–114
constants defined in, 113
recordDeleted() method
for RecordListener interface, 112
RecordEnumeration
using to walk through record store records, 110–112
RecordEnumeration interface
basic operation of, 114–115
keeping up-to-date, 115
RecordFilter interface
code example for, 113
RecordListener interface
methods, 112
RecordMIDlet
source code for, 109–110
records
adding to a record store, 107
deleting and replacing, 108

in record stores, 103
retrieving from a record store, 107–108
working with, 106–108
RecordStore class
code for a class that encapsulates access, 110–112
for getting RecordStore record information, 108
inside a, 107
purposes of, 104
RecordStore listeners
methods for managing, 112
RecordStore queries
performing, 113–115
reference pixel
for Sprite transformations, 265
Reflection API
lack of support for in CLDC, 42
releaseTarget() method
for flushing rendered image to 2D Graphics, 277
remote devices
access to, 204
RemoteDevice instance
security methods to authenticate and encrypt connections, 204
removeCommand() method
for managing Item commands, 76
removeContact() method
calling on the ContactList interface, 137
rename() method
renaming a file or directory with, 121–122
render() method
calling to draw a 3D frame, 289
of Graphics3D, 277
rendering attributes
in an M3G class, 286–287
repaint() method
for refreshing custom item's appearance, 92
using to paint a Canvas, 232
requests and responses
for HTTP, 145
Research In Motion BlackBerry Java Development Environment
website address for, 12
reset() method
for moving back to beginning of selected records, 115
resolution
changing of tone sequence, 317
resource files
retrieving from your MIDlet suite's JAR file, 48
using, 116
ResponseCodes
partial list of OBEX, 218
resume() method
absence of in CLDC, 42
resumeRequest() class
for making MIDlet Active, 30
retained mode
high-level access to a scene graph via, 297–298
vs. immediate mode, 297–303
steps for using in M3G API, 298
working with, 298–301
retained mode 3D world
loading, 301–302
rendering a frame in, 302–303
retrieving the active camera in, 302
using find() method to locate objects withing, 302
RetainedCanvas
for interacting with retained mode 3D World, 299–301
RFC 2246
website address for information about, 157
RFC 2806
website address, 31
RFC 2965
provisions for return of multiple cookie values, 154
RMMIDlet
code for, 299–301
root names
static method for discovering, 124
rootChanged() method
of FileSystemListener interface, 123
ROT transformations
function of, 244–245
Run via OTA tool
for testing your MIDlet's installation behavior, 163
Runtime class
providing access to JVM and system-wide resources, 44

S

SADP. *See* Service Application Discovery Profile (SADP)
saving
  user preferences, 108–112
Schneier, Bruce
  Applied Cryptography: Protocols, Algorithms, and Source Code in C (John Wiley & Sons, 1995) by, 344
Screen class
  contents of in Displayable instance, 54
  the four children of, 55
screens, 61
SD card
  code for getting input stream to a text file on, 119
SDDB. *See also* Service Discovery Database (SDDB)
  registering ServiceRecord with, 207
searchServices() method
  for discovering services, 202–203
Secret Data (SD) cards, 117
secure HTTP. *See* HTTP connections
Secure Sockets Layer (SSL)
  HTTPS running atop, 157–158
security
  and FileConnection Optional Package, 124
  for indicating if authentication and encryption should be used, 203
  of MIDP, 8–9
select button
  on J2ME Wireless Toolkit emulator, 19
selectService() method
  for obtaining a connection using UUID, 204
  using to find a service, 203
Sender class
  for sending SMS messages, 178–179
SENSITIVE flag
  function of, 62
Serial Port Profile (SPP)
  for sending/receiving streamed data between devices, 199
server session ID
  parsing and packaging, 153
  requirements for in MIDP world, 153
  sending to a server, 153
server-side components
  likelyhood of in Jargoneer example, 21–23
Service Application Discovery Profile (SADP)
  enabling Bluetooth applications to discover services, 199
service discovery callback
  methods used for, 203
Service Discovery Database (SDDB)
  used by Bluetooth during service discovery, 205–206
Service Discovery Protocol (SDP)
  used for service discovery between devices, 199
ServiceRecord
  common attribute IDs, 205
  registering with SDDB, 207
  and service attributes, 205–206
ServiceRecord class
  methods for manipulation of attributes, 206
services
  a simpler way to discover, 203–204
  using searchServices() method for discovering, 202–203
session ID. *See* server session ID
session permissions, 36
session tracking
  using cookies for, 152–157
set() method
  for editing lists, 70
setAddress() method
  for setting outgoing message destination address, 173
setCurrent() method
  function of, 56
setDefaultCommand() method
  for setting an Items default command, 76
setFitPolicy() method
  for handling text width issues in Lists, 71
setFont() method
  calling to use a new font for subsequent text, 240
  for specifying List element font, 71
  in StringItem class, 79
setGrayScale() method
  for grayscale devices, 236
setIdentity() method
  calling on the Transform, 289
setImage() method
  for changing a Sprite source image, 263
setIndicator() method
  passing a Gauge to an Alert's, 65

setInitialInputMode() method
function of in TextBox class, 63
function of in TextField class, 80
setItemCommandListener() method
assigning a command listener with, 76
setLabel() method
inherited from Item, 79
in Item class, 75
setLayout() method
for accessing Item class layout directive, 77
setLoopCount() method
for controlling audio clip play times, 316
setMediaTime() method
for jumping to a particular point in an audio clip, 316
setMessageListener() method
for adding a MessageListener on the MessageConnection, 172
setNormals() method
using in VertexBuffer, 286
setPositions() method
using in VertexBuffer, 286
setPreferredSize() method
using for Items, 77
setShininess() method
for controlling how shiny a material appears, 287
setText() method
for accessing and adjusting string value, 79
setTimeout() method
changing an Alert's timeout with, 64
setTitle() method
for accessing title, 60
set-top boxes
understanding J2ME for, 1–3
setValue() method
modifying value of a Gauge instance with, 83
setViewWindow() method
using in LayerManager, 260
setVisible() method
for accessing a layer's visibility, 259
SHA-1 message digest object
creating, 347
shapes
Graphics class methods for drawing and filling, 233–234
shared secret
password as, 346–356
Short Message Service (SMS), 165–194
for cell phone users, 165
the killer app for wireless, 165–166
sending binary messages, 169–170
sending text messages, 170
ubiquitous nature of, 165
and Wireless Messaging API (WMA), 166
showNotify() method
calling of by MIDP implementation, 93
shrinking layout value
for Form items, 77
SimpleItem
code example, 90
code of a MIDlet that demonstrates, 91
singleton PIM instance
obtaining, 131
size() method
for returning the number of List elements, 71
sizeChanged() method
calling after setting Canvas full screen mode, 232
calling by MIDP implementation, 93
SMS. *See* Short Message Service (SMS)
SMS APIs
working with, 173–181
SMS messages
code for opening a connection and sending messages, 170
code for sending and receiving, 174-177
vs. multipart messages, 182
a nonblocking approach to receiving, 172
receiving, 170–171
sending, 178–180
sending binary, 169–170
sending text messages, 170
SMSMIDlet
code for, 174–177
creating an independent receive thread, 178
GUI of, 174
for sending and receiving SMS messages, 173–178
testing with WTK 2.x WMA console, 180
soft buttons
defined, 57
on J2ME Wireless Toolkit emulator, 19
solid outlines
code example for drawing, 237

sound, music, and video
quick start with MMAPI, 305–311
Spacer
using in a Form, 79
special effects
in Game API, 272
Sprite animation, 263–264
Sprite class
constants, 244–245
Sprites
animating, 263–264
applying a transformation to, 264
changing current frame sequence for, 264
changing source image, 263
collision detection with, 267
collision rectangle for collision detection, 266
copying, 267
creating, 263
creating new and setting frame sequence, 264
setting current position of reference pixel, 266
transforming, 264–266
using, 263–267
stack
defined, 1
start content ID
methods for designating, 183
start() method
calling on a freshly created Player, 315
startApp() method
calling, 29–30
importance of calling getDisplay() method after, 55–56
STARTED state
for Players, 315
states
of a Player's life cycle, 314–315
static tile set
changing on an existing TiledLayer, 261
StationSign custom item
code example for, 97–100
an example, 97–100
MIDlet that demonstrates, 101–102
StealthMIDlet
a data encryption MIDlet, 359–361
deployment issues, 364
main screen, 357
for securing network data, 359–361
suggested enhancements for, 364
StealthServlet
example of secret message sent back from, 357
source code for, 362–363
suggested enhancements for, 364
stop() method
absence of in CLDC, 42
function when called on a STARTED Player, 315
straight lines
drawLine() method for drawing, 92
StreamConnectionNotifier
creating and the corresponding ServiceRecord, 206
streams
in java.io package, 45–48
String class
in CLDC java.lang package, 43
stringArraySize() method
function of in ContactList interface, 137
StringBuffer class
in CLDC java.lang package, 43
stringElements parameter
function of, 69
StringItem labels
code for, 78
controlling appearance of, 79
working with, 78–79
Strings and StringBuffers
effect of on memory use, 336
stroke style
maintained by Graphics class, 236–237
submesh
defining with a TriangleStripArray, 286
giving an appearance, 286–287
Sun Java Studio Mobility
website address, 12
Sun's J2ME Wireless Toolkit (J2MEWTK). *See* J2ME Wireless Toolkit (J2MEWTK)
Sun's J2ME Wireless Toolkit emulators. *See* J2ME Wireless Toolkit emulators
Superscape
Swerve tool for creating .m3g files, 298
supported fields
checking for, 135
Sweep MIDlet
source code for, 252–254

SweepCanvas animation
running on the WTK default emulator, 252
SweepGame MIDlet
for displaying SweepGameCanvas, 257
Swerve tool
by Superscape for creating .m3g files, 298
symmetric cipher, 344
System class
static methods provided by, 44–45

T

TDMA
support for SMS, 165
tempo value
setting the default for tone sequence, 317
text
measuring in Font class, 242–243
text labels. *See* StringItem labels
text messaging
between cell phones without Internet access, 165–166
Wireless Messaging API (WMA) for, 165–194
text SMS messages
sending, 170
TEXT_WRAP_DEFAULT value
from Choice interface, 71
TEXT_WRAP_OFF value
from Choice interface, 71
TEXT_WRAP_ON value
from Choice interface, 71
TextBox
creating, 62
in Jargoneer MIDlet, 21
specifying parameters for creating, 61–63
specifying type of input required with constants, 62
TextBox class
setInitialInputMode(String characterSubset) method, 63
TextCanvas
example of, 239
TextField class
constants from, 62
creating, 80
function of, 79–80
input constants and flags, 80
texture coordinate
for mapping a texture to a square surface, 296–297
texture mapping
on a 3D surface, 295–296
thread naming
support in CLDC 1.1, 42
Ticker class
function of, 60
tickers
adding to a screen, 60–61
need for avoiding use of with Forms, 74
tiled layers
size and numbering of, 260–261
tile image layouts, 260–261
using, 260–263
TiledLayer
creating and initializing, 261–262
drawing on a Graphics object, 260–261
retrieving dimensions of, 261
retrieving number of columns and rows in, 261
tiles
creating and using animated, 262–263
Time zone classes
function of in CLDC/MIDP, 52
function of in J2SE, 52
timed alerts
function of, 63
Timer class
in MIDP, 51
timers
included in MIDP, 51
TimerTask class
in MIDP, 51
times and dates
J2SE array of classes for specifying, 51–52
TimeZone
specifying in DateField class, 81
TLS
lack of client authentication by, 345
for network data security, 345
tone sequence
changing the resolution of, 317
code samples to help write them, 318–321
default values, 317–318
defining reusable blocks of tones in, 318
setting the default tempo value, 317
setting volume during, 318
tone sequence Player
obtaining with createPlayer() method, 316–317

ToneControl
  defined by ABB, 316
ToneControl object
  giving tone sequence Player a tone sequence with, 317–321
tones
  defining reusable blocks of in tone sequence, 318
totalMemory() method
  function of, 44
transform arguments
  for Sprite class, 265
Transform methods
  showing, 288
transform parameter
  for drawRegion() method, 244
Transforms
  for moving 3D objects about, 288–289
Transport Layer Security (TLS)
  HTTPS running atop, 157–158
TravelList source code
  code example, 72–73
traversal
  defined, 94
  internal, 95
traverse() method
  function of, 95–96
  information passed to in code example, 96
traverseOut() method
  function of, 95–96
triangle strips
  applying texture image to, 296–297
  defining for the corner submesh, 295
  understanding use of in M3G, 290
triangle vertices
  defining, 284–285
TriangleCanvas
  code for rotation of a triangle in 3D, 281–283
  modifying to rotate a square, 290–291
TriangleMIDlet
  code to contain the TriangleCanvas, 283–284
  creating without using M3G code, 278
  rotating a 2D triangle, 278–279
  rotating a triangle around the x-axis, 280
TriangleStripArray
  defining a submesh with, 286
TwoAlerts
  code example of, 65–66

U

UDPDatagramConnection interface
  new methods in, 159
UNEDITABLE flag
  function of, 62
UNREALIZED state
  for Players, 314–315
unregisterConnection() method
  for removing a connection-to-MIDlet mapping, 163
URL and path information
  method for getting, 122–123
URLBuilder helper class
  for assembling GET URLs, 353
usedSize() method
  for finding used up size of the storage area, 121
user classloading
  lack of support for in CLDC, 42
user interface
  creating MIDP, 53–66
  generalized for Jargoneer MIDlet, 20–21
  optimizing for application speed, 340
  programming a custom, 231–254
user preferences
  saving in RecordStore, 108–112
utilities
  WMA console, 180
UUID (Universally Unique identifier)
  defined, 199
  using to discover a service, 203–204

V

vCard 3.0 specification
  standard fields for Contact built on, 133–134
verbufVertexBuffer
  creating, 286
verifyFileConnectionSupport() method
  function of, 128–129
verifyPIMSupport() method
  function of, 140
VertexArray
  defining the position of an initial triangle in, 284
  set() methods for, 284–285

VertexBuffer
combining vertex information into, 285–286
methods used in, 286
using a float bias in, 286
using a float scale in, 286
using setNormals() method in, 286
using setPositions() method in, 286
vertical values
for layout of Form items, 77
vertices. *See* triangle vertices, defining
vibrate() method
function of, 56
video
on custom Canvas, 322
displaying on your phone, 322–325
on an Item within a Form, 322–325
using MMAPI to play on your phone, 321–325
VideoControl
using to snap a still picture of a video, 325–326
VideoMIDlet code
for playing video using MMAPI, 323–325
view window
in LayerManager, 260
volatile memory
defined, 3
volume
setting during tone sequence, 318
VolumeControl
defined by ABB, 316
using to set playback volume to half its maximum, 316

W

wakeup call
requesting for MIDlets, 30
WCDMA
support for SMS, 165
website address
for Ant build file that invokes ProGuard 3.2 obfuscator, 365
for article about using ProGuard obfuscator, 25
for Autodesk, 298
for Bluetooth “Assigned Numbers” document, 201
for Borland JBuilder X Mobile Edition, 12
CLDC home page, 5
for comprehensive list of MIDP devices, 27
for downloading Bouncy Castle cryptography package, 345–346
for downloading MIDP reference implementation, 11
for downloading PatchyMIDlet, 160
for downloadingJ2ME Wireless Toolkit (J2MEWTK), 11
for Eclipse J2ME Plugin, 12
for HI Corporation, 298
for IBM WebSphere Studio Device Developer, 12
for information about client certificates and signatures, 345
for information about cookie strings, 153
for information about HTTPS and TLS in MIDP, 345
for information about Jargon File, 12
for information about Java Media Framework, 305
for information about KVM, 4
for information about OpenGL ES, 276
for information about RFC 2246, 157
for information about SSL, 157
Internet Mail Consortium, 133
for introduction to Ant and MIDP, 25
for Java Community Process (JCP), 2
JSR 120, 166
for JSR 135 MMAPI details, 305
JSR 177 (Security and Trust Services for J2ME), 346
for JSR 185 specification, 6
JSR 205, 166
for JSR 68 (Building Blocks) definition, 6
for Knudsen series on security and cryptography, 344
for list of current JSRs, 2
for list of J2ME configurations, profiles, and optional APIs, 2
for list of obfuscators, 25
for MIDP information, 6
for NetBeans IDE 4.x, 12
for Nokia Developer’s Suite for J2ME, 12
for the PeekAndPick application, 334
for PersonalJava, 5
for the pogoroo.m3g file, 299
for ProGuard 3.2 information, 365

for Research In Motion BlackBerry Java Development Environment, 12
for RFC 2806, 31
for sobering measurements from real devices, 105
for specialized Ant tasks for MIDlet suite builds, 27
for Sun Java Studio Mobility, 12
for Superscape, 298
wireless application security
importance of, 35–37
Wireless Messaging API (WMA). *See also* WMA API
for cell phone text messaging, 165–194
website address for JSR for version 1.1, 166
Wireless Messaging API 1.0 (WMA)
JTWI-compliant device specification for, 6
Wireless Messaging API 2.0
website address for JSR, 166
Wireless Toolkit 2.x
accessing the Bluetooth Control Center within, 205
Wireless Toolkit emulator
running Pacer class in, 235
WMA. *See also* Wireless Messaging API (WMA)
and SMS, 166
WMA 2.0
Multimedia Message Service (MMS) support in, 165
multimedia messaging with, 181–185
WMA API. *See also* Wireless Messaging API (WMA); Wireless Messaging API 2.0; WMA; WMA 2.0
extending with GCF, 167
function of, 167–169
WMA console
information for MMS testing on, 192–193
sending and receiving SMS messages using SMSMIDlet and, 181
sending an MMS message to MMSMIDlet via, 193
Writer character stream
in MIDP for working with Unicode characters, 48
WTK 2.x camera simulation, 326–329
WTK 2.x WMA console
testing SMSMIDlet with, 180
WTK emulators
Bluetooth dating service running on, 209
capturing images using simulated video on, 326

Z

z order
of layers, 259